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A COMPARISON OF RESPIRABLE DUST SAMPLING INSTRUMENTS IN A DUST CHAMBER - NOVEMBER 1985

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by

G.W. Bonnell*, G.R. Corbett** and D.A. Young**

ABSTRACT

This report presents the analysis of respirable dust measurements obtained using a variety of sampling systems in a dust chamber. These comparative tests were conducted by CBCRL staff members using the Mining Research Laboratory's (MRL) facilities at Elliot Lake during November 1985. Respirable "coal and silica" dust measurements were then statistically analyzed and presented.

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COMPARAISON D'INSTRUMENTS D'ÉCHANTILLONNAGE DES POUSSIÈRES INHALABLES DANS UNE CHAMBRE DE POUSSIÈRES - NOVEMBRE 1985

par

G.W. Bonnell*, G.R. Corbett** et D.A. Young**

RÉSUMÉ

Le présent rapport expose l'analyse des mesures des concentrations de poussières inhalables obtenues à partir de divers systèmes d'échantillonnage dans une chambre de poussières. Ces essais comparatifs ont été effectués par le personnel du Laboratoire de recherche sur le charbon du Cap-Breton dans les installations du Laboratoire de recherche minière (LRM) d'Elliot Lake en novembre 1985. On a ensuite fait l'analyse statistique et la présentation des mesures des concentrations de poussières de charbon et de silice inhalables.

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CONTENTS

	Page
ABSTRACT	1
RESUME	iii
INTRODUCTION	1
INSTRUMENTATION	1
TRIAL PROCEDURES	3
RESULTS AND ANALYSIS	5
Calculation of Respirable Dust Concentrations	5
Sampling Systems vs Casella Type 113A Average	12
Sampling Systems vs Hexhlet Average	12
BMRC Casella Cyclones vs Casella Type 113A Average	12
BMRC Casella Cyclones vs Hexhlet Average	18
Comparative Tests of BMRC Casella Cyclones	18
Conversion of Sampling System Results to Casella Gravimetric Sampler Type 113A Basis and Hexhlet Basis	22
DISCUSSION	22
CONCLUSIONS	29
ACKNOWLEDGEMENTS	30
REFERENCES	30
APPENDIX A	31
APPENDIX B	37
APPENDIX C	46
APPENDIX D	55
APPENDIX E	74

TABLES

No.		Page
1.	Respirable dust sampling systems	4
2.	Trial No. 1	6
3.	Trial No. 2	7
4.	Trial No. 3	8
5.	Trial No. 4	9

No.		Page
6.	Trial No. 5	10
7.	Trial No. 6	11
8.	Respirable dust concentrations for Trials 1 through 6	13
9.	Various sampling systems vs Casella Type 113A average	15
10.	Various sampling systems vs Hexhlet average	16
11.	BMRC cyclones vs Casella gravimetric sampler Type 113A average	17
12.	BMRC cyclones vs Hexhlet gravimetric sampler average	19
13.	Z-score transformations for BMRC cyclones	21
14.	Respirable dust measurements calculated to Casella Type 113A basis	24
15.	Respirable dust measurements calculated to Hexhlet basis	26

FIGURES

No.		Page
1.	Respirable dust concentration (BMRC cyclone) vs BMRC cyclone No.	20
2.	Sample standard deviation vs average concentration of BMRC cyclones	23

INTRODUCTION

The respirable dust research program of the Cape Breton Coal Research Laboratory (CBCRL) has been described previously (1). The long-term objective of this research program is to lower coal miners' occupational exposure to airborne respirable dust and thus reduce risk of the development and progression of pulmonary disease in coal miners.

As there are numerous dust sampling systems available, utilizing various techniques of dust separation, collection and monitoring, they must be tested for their reproducibility and comparability. These tests can be conducted in either the field (e.g. tests conducted in underground coal mines) or in a controlled laboratory environment (e.g. a dust chamber).

This report presents the respirable dust results obtained using a variety of sampling systems in a dust chamber. These comparative tests were conducted by CBCRL staff members (G. Corbett and D. Young) at the Mining Research Laboratory's (MRL) facilities at Elliot Lake during November 1985. The concentration measurements of respirable coal and silica dust were then statistically analyzed and graphs presented in this report. These results will finally be compared with analysis results obtained in the various field tests conducted at the Cape Breton Development Corporation (CBDC) underground coal mines and presented later in another report.

INSTRUMENTATION

Instrumentation for the tests conducted at MRL, Elliot Lake consisted essentially of the following: a) dust chamber, b) various sampling systems and c) semi-microbalance.

The dust chamber was comprised of a wooden and plexiglass structure which was approximately 2 m x 2 m x 3 m. Dust samples were continuously injected by means of compressed air and distributed by perforated pipes running along both sides of the chamber. A circulating fan inside the chamber was used to keep the dust well mixed and the dust laden air was vented out through the top of the chamber. A vacuum pump was situated on the roof exterior of the dust chamber and connected to pressure gauges and "critical orifices" by metal tubing. This enabled flow rates to be adjusted for those

sampling systems connected to this system. (Samplers connected to this vacuum system can be identified by a "g" under the heading "Pump #, Gauge #" in Tables 2 - 7). Instruments were set up within a 1 m^2 area within the dust chamber. Small ports on the sides of the chamber enabled vacuum pump lines to be connected to the appropriate dust sampling systems inside.

The sampling systems used are as follows:

1) Eighteen BMRC Casella cyclones T13026/2 - airflow through the cyclone produces a centrifugal motion which tends to separate the larger non-respirable particles from the respirable particles. Non-respirable particles are collected in a removable "dust pot" at the bottom of the cyclone while respirable particles are collected on a pre-weighed 37 mm filter. The first 12 of these samplers were connected to DuPont (Pump P2500A) constant flow pumps with a nominal flow rate of 1.9 l/min, while the remaining cyclones (13-18) were connected to the forementioned vacuum system, also with a nominal flow rate of 1.9 l/min.
2) Two Casella Type 113A gravimetric samplers - the Casella Type 113A is comprised of a horizontal elutriator to separate non-respirable dust from respirable dust (gravimetric separation), a piston pump providing a flow rate of 2.5 l/min and a filter holder containing a 55 mm fiberglass filter. This sampler is the standard reference sampler used by CBCRL and normally all sampling system results are corrected to the Casella Type 113A basis (MRE equivalent concentration) (2,3).
3) Two Hexhlet gravimetric samplers - the Hexhlet consists of a horizontal elutriator, a critical orifice and a filter holder containing a 55 mm fiberglass filter. These high volume samplers (50 l/min) are ideal for calibration purposes but tend to be too cumbersome for routine underground field tests.
4) SIMSLIN II - the SIMSLIN II is a portable dust monitor which incorporates both a gravimetric and a light-scattering technique which provides continuously recorded and displayed respirable dust levels. The SIMSLIN has a horizontal elutriator for dust separation, a flow rate of 0.625 l/min and a filter holder containing a 47 mm fiberglass filter.

5) Five Dorr-Oliver 10 mm nylon cyclones - these cyclones operate on the same principal as the BMRC Casella cyclones. As the name implies they are made of nylon. Respirable dust samples were collected on a pre-weighed 37 mm fiberglass filter and a nominal flow rate of 2.0 1/min was used.
6) Five 10 mm nylon cyclones (MRL) - these cyclones operate essentially the same way as the Dorr-Oliver cyclones, however, respirable dust was collected on a pre-weighed 25 mm silver membrane filter and a nominal flow rate of 1.7 1/min was used.
7) Two CAMPEDS (MRL) - the CAMPEDS (Canadian mining personal dust sampler) was developed by the Elliot Lake Laboratory for use as a personal dust sampler (5). The sampler has a two-stage impaction orifice to separate non-respirable dust from respirable dust. (Large particles or non-respirable dust impact upon the deflecting obstacle or impacting surface, while the smaller respirable dust follows the deflected airstream where it is collected on a filter.) Dust samples were collected on a pre-weighed 25 mm silver membrane filter with a flow rate of 2.0 1/min.

Filters were weighed using a Mettler AE-163 semi-microbalance and were weighed to the nearest .01 mg.

See Table 1 for a list of sampling systems.

TRIAL PROCEDURES

As mentioned previously, the comparative tests of various sampling systems was undertaken by CBCRL staff at MRL facilities at Elliot Lake. The following is a brief description of the procedures used for these comparative tests or trials:

1) Samplers were cleaned and calibrated in preparation for the tests.
2) Filters were weighed on a Mettler AE-163 semi-microbalance to the nearest .01 mg and then loaded into the appropriate samplers.
3) Sampling systems were set up within the dust chamber and the SIMSLIN II was turned on followed by the Casella Type 113A samplers.

Table 1 - Respirable dust sampling systems

Samplers	Number of Units	Flow Rate of Sampling System (l/min)	Size and Type of Filter Used
SIMSLIN II Dust Monitoring System	1	0.625	47 mm fiberglass
Casella Type 113A Gravimetric Sampler	2	2.50	55 mm fiberglass
(BMRC)* Casella Cyclone Ti3026/2	18	1.90	37 mm fiberglass
Dorr-Oliver 10 mm Nylon Cyclone	5	2.0	37 mm fiberglass
(MRL)** Casella Hexhlet	2	50.0	55 mm fiberglass
(MRL)** 10 mm Nylon Cyclone	5	1.70	25 mm silver membrane
(MRL)** CAMPEDS	2	2.0	25 mm silver membrane

*BMRC - British Medical Research Council

**MRL - Mining Research Laboratory

4) Dust was continuously injected into the dust chamber. The fan and exhaust system were turned on and the dust levels were allowed to equilibrate. Then all the remaining samplers were turned on.
5) After a period of approximately 1 to 3 hours, the dust injection system and the circulating fan was turned off. (The duration of the test was determined by simply deciding when enough dust for weighing purposes had been collected on the filters.) The samplers which could be turned off from outside the dust chamber were turned off. When the dust levels subsided after several minutes, the Casella Type 113A samplers and the SIMSLIN II were turned off.
6) Samplers were taken from the dust chamber and filters removed and weighed. SIMSLIN light-scattering results were retrieved from the SIMSLIN's "SIMSTOR 1" memory pack.
7) Steps 1) through 6) were repeated for each of the six trials.

NOTE: The samplers, dust chamber, vacuum lines, etc. were cleaned before and after each test; particularly between Trials 5 and 6 which used coal dust and silica dust respectively. Also, the dust chamber was "conditioned" by operating the dust chamber with the appropriate dust sample prior to each of the trials.

RESULTS AND ANALYSIS

CALCULATION OF RESPIRABLE DUST CONCENTRATIONS

Results of the comparison of the sampling systems for the six trials are presented in Tables 2 to 7. Due to the sampling procedures utilized, sampling systems were not turned on at the same time. (As noted previously, the SIMSLIN and Casella Type 113A samplers were turned on prior to and turned off after the other samplers in order to protect the operators from the dust.) Delays of up to several minutes occurred in some cases. To remedy this situation, the results of the sampling systems were adjusted to match the times that the Casella gravimetric Type 113A samplers were turned on. Thus, for example, if a sampling system was turned on five minutes earlier or five minutes later, then that sampling system's results would be adjusted or corrected to match the time that the Casella Type 113A samplers were turned on. These corrections were done by using the integrated results

Table 2 - Trial No. 1

Filter Number	Filter Type	Initial Weight (mg)	Final Weight (mg)	Blank Change	Pump # Gauge #	Holder # or Type	Initial Flow (l/min)	Final Flow (l/min)	Nominal Flow (l/min)	Pump Run Time (min)	Sample Weight (mg)	Conc. (mg/m^3)	Correction Factor	Corrected Conc. (mg/m^3)
1-1	37 mm F.G.	78.31	79.64	0.05	d-1	c-1	1.94	1.94	1.900	161	1.28	4.18	1.01048	4.23
1-2	37 mm F.G.	76.40	77.77	0.05	d-2	c-2	1.90	1.93	1.900	161	1.32	4.32	1.01048	4.36
1-3	37 mm F.G.	75.44	76.77	0.05	d-3	c-3	1.89	1.92	1.900	161	1.28	4.18	1.01048	4.23
1-4	37 mm F.G.	74.66	75.96	0.05	d-4	c-4	1.90	1.79	1.900	161	1.25	4.09	1.01048	4.13
1-5	37 mm F.G.	74.89	76.31	0.05	d-5	c-5	1.90	1.94	1.900	161	1.37	4.48	1.01048	4.53
1-6	37 mm F.G.	74.97	76.29	0.05	d-6	c-6	1.88	1.92	1.900	161	1.27	4.15	1.01048	4.20
1-7	37 mm F.G.	75.52	77.13	0.05	d-7	c-7	1.90	1.96	1.900	161	1.56	5.10	1.01048	5.15
1-8	37 mm F.G.	76.74	78.36	0.05	d-8	c-8	1.90	1.95	1.900	161	1.57	5.13	1.01048	5.19
1-9	37 mm F.G.	76.33	77.91	0.05	d-9	c-9	1.86	1.92	1.900	161	1.53	5.00	1.01048	5.05
1-10	37 mm F.G.	75.64	77.23	0.05	d-10	c-10	1.92	1.99	1.900	161	1.54	5.03	1.01048	5.09
1-11	37 mm F.G.	73.59	74.79	0.05	d-11	c-11	1.89	1.98	1.900	161	1.15	3.76	1.01048	3.80
1-12	37 mm F.G.	75.24	76.61	0.05	d-12	c-12	1.86	1.95	1.900	161	1.32	4.32	1.01048	4.36
1-13	37 mm F.G.	76.26	77.71	0.05	g-1	c-13	1.90	1.90	1.900	161	1.40	4.58	1.01048	4.62
1-14	37 mm F.G.	76.24	77.76	0.05	g-23	c-14	1.90	1.90	1.900	161	1.47	4.81	1.01048	4.86
1-15	37 mm F.G.	77.25	78.63	0.05	g-24	c-15	1.90	1.90	1.900	161	1.33	4.35	1.01048	4.39
1-16	37 mm F.G.	74.29	75.82	0.05	g-6	c-16	1.90	1.90	1.900	161	1.48	4.84	1.01048	4.89
1-17	37 mm F.G.	74.76	76.33	0.05	g-5	c-17	1.90	1.90	1.900	161	1.52	4.97	1.01048	5.02
1-18	37 mm F.G.	74.63	75.95	0.05	g-4	c-18	1.90	1.90	1.900	161	1.27	4.15	1.01048	4.20
1-41	55 mm F.G.	651.76	653.45	0.05	Cas 3949	Cas 3949	2.49	2.56	2.525	168	1.64	3.87	1.00000	3.87
1-42	55 mm F.G.	630.52	632.30	0.05	Cas 3928	Cas 3928	2.46	2.50	2.480	168	1.73	4.15	1.00000	4.15
1-43	47 mm F.G.	90.27	90.97	0.05	SIMSLIN	SIMSLIN	0.625	0.625	0.625	178	0.65	5.89		6.40
					SIMSLIN	L.S.(SIM)				178		2.6		2.8
					SIMSLIN	L.S.(CHART)				178				2.87
1-44	55 mm F.G.	3123.44	3150.81	0.05	g-15	Hex A	50.00	50.00	50.000	161	27.32	3.39	1.01048	3.43
1-45	55 mm F.G.	3129.81	3154.37	0.05	g-12	Hex B	50.00	50.00	50.000	161	24.51	3.04	1.01048	3.08
1-1298	25 mm S.M.	133.37	134.05	0.00	g-2	E-1	1.70	1.70	1.700	161	0.68	2.48	1.01048	2.51
1-1299	25 mm S.M.	135.28	135.97	0.00	g-7	E-3	1.70	1.70	1.700	161	0.69	2.52	1.01048	2.55
1-1300	25 mm S.M.	137.09	137.73	0.00	g-8	R-1	1.70	1.70	1.700	161	0.64	2.34	1.01048	2.36
1-1301	25 mm S.M.	123.07	123.76	0.00	g-21	R-2	1.70	1.70	1.700	161	0.69	2.52	1.01048	2.55
1-1302	25 mm S.M.	121.36	122.11	0.00	g-22	E-2	1.70	1.70	1.700	161	0.75	2.74	1.01048	2.77
1-1303	25 mm S.M.	118.28	119.34	0.00	g-9	CAMPED 5/33	2.00	2.00	2.000	161	1.06	3.29	1.01048	3.33
1-1304	25 mm S.M.	112.39	113.48	0.00	g-26	CAMPED 6/26	2.00	2.00	2.000	161	1.09	3.39	1.01048	3.42

Table 3 - Trial No. 2

Filter Number	Filter Type	Initial Weight (mg)	Final Weight (mg)	Blank Change	Pump # Gauge #	Holder # or Type	Initial Flow (l/min)	Final Flow (l/min)	Nominal Flow (l/min)	Pump Run Time (min)	Sample Weight (mg)	Conc. (mg/m^3)	Correction Factor	Corrected Conc. (mg/m^3)
2-1	37 mm F.G.	74.02	74.93	0.03	d-1	c-1	1.94	1.99	1.90	49	0.88	9.45	0.99736	9.43
2-2	37 mm F.G.	76.75	77.79	0.03	d-2	c-2	1.93	1.95	1.90	49	1.01	10.85	0.99736	10.82
2-3	37 mm F.G.	74.99	75.99	0.03	d-3	c-3	1.92	1.97	1.90	49	0.97	10.42	0.99736	10.39
2-4	37 mm F.G.	73.43	74.41	0.03	d-4	c-4	1.90	1.92	1.90	49	0.95	10.20	0.99736	10.18
2-5	37 mm F.G.	77.55	78.51	0.03	d-5	c-5	1.94	1.93	1.90	49	0.93	9.99	0.99736	9.96
2-6	37 mm F.G.	75.63	76.66	0.03	d-6	c-6	1.92	1.91	1.90	49	1.00	10.74	0.99736	10.71
2-7	37 mm F.G.	69.75	70.74	0.03	d-7	c-7	1.90	1.94	1.90	49	0.96	10.31	0.99736	10.28
2-8	37 mm F.G.	68.61	69.61	0.03	d-8	c-8	1.95	1.95	1.90	49	0.97	10.42	0.99736	10.39
2-9	37 mm F.G.	69.28	70.26	0.03	d-9	c-9	1.92	1.91	1.90	49	0.95	10.20	0.99736	10.18
2-10	37 mm F.G.	71.35	72.35	0.03	d-10	c-10	1.88	1.88	1.90	49	0.97	10.42	0.99736	10.39
2-11	37 mm F.G.	69.40	70.37	0.03	d-11	c-11	1.89	1.90	1.90	49	0.94	10.10	0.99736	10.07
2-12	37 mm F.G.	70.78	71.81	0.03	d-12	c-12	1.95	1.94	1.90	49	1.00	10.74	0.99736	10.71
2-13	37 mm F.G.	69.98	71.04	0.03	g-1	c-13	1.90	1.90	1.90	50	1.03	10.84	1.00000	10.84
2-14	37 mm F.G.	70.14	71.20	0.03	g-23	c-14	1.90	1.90	1.90	50	1.03	10.84	1.00000	10.84
2-15	37 mm F.G.	69.08	70.13	0.03	g-24	c-15	1.90	1.90	1.90	50	1.05	11.05	1.00000	11.05
2-16	37 mm F.G.	68.60	69.69	0.03	g-6	c-16	1.90	1.90	1.90	50	1.06	11.16	1.00000	11.16
2-17	37 mm F.G.	70.72	71.82	0.03	g-5	c-17	1.90	1.90	1.90	50	1.07	11.26	1.00000	11.26
2-18	37 mm F.G.	69.76	70.69	0.03	g-4	c-18	1.90	1.90	1.90	50	0.90	9.47	1.00000	9.47
2-21	55 mm F.G.	633.90	634.95	0.03	Cas 3949	Cas 3949	2.56	2.56	2.56	50	1.02	7.97	1.00000	7.97
2-20	55 mm F.G.	634.74	635.84	0.03	Cas 3928	Cas 3928	2.50	2.50	2.50	50	1.07	8.56	1.00000	8.56
2-19	47 mm F.G.	91.82	92.00	0.03	SIMSLIN SIMSLIN SIMSLIN	SIMSLIN L.S.(SIM) L.S.(CHART)	0.625	0.625	0.625	53 53 53	0.15	4.56		4.61 6.66
2-22	55 mm F.G.	2987.91	3011.80	0.03	g-15	Hex A	50.00	50.00	50.00	50	23.86	9.54	1.00000	9.54
2-23	55 mm F.G.	3043.96	3068.41	0.03	g-12	Hex B	50.00	50.00	50.00	50	24.42	9.77	1.00000	9.77
2-1305	25 mm S.M.	114.74	115.30	0.00	g-2	E-1	1.70	1.70	1.70	50	0.56	6.59	1.00000	6.59
2-1306	25 mm S.M.	143.52	144.45	0.00	g-26	CAMPED 6/26	2.00	2.00	2.00	50	0.93	9.30	1.00000	9.30
2-1307	25 mm S.M.	144.87	145.84	0.00	g-9	CAMPED 5/33	2.00	2.00	2.00	50	0.97	9.70	1.00000	9.70
2-1308	25 mm S.M.	122.05	122.65	0.00	g-21	R-2	1.70	1.70	1.70	50	0.60	7.06	1.00000	7.06
2-1309	25 mm S.M.	142.05	142.63	0.00	g-8	R-1	1.70	1.70	1.70	50	0.58	6.82	1.00000	6.82
2-1310	25 mm S.M.	131.59	132.15	0.00	g-22	E-2	1.70	1.70	1.70	50	0.56	6.59	1.00000	6.59
2-1311	25 mm S.M.	127.10	127.65	0.00	g-7	E-3	1.70	1.70	1.70	50	0.55	6.47	1.00000	6.47

Table 4 - Trial No. 3

Filter Number	Filter Type	Initial Weight (mg)	Final Weight (mg)	Blank Change	Pump # Gauge #	Holder # or Type	Initial Flow (l/min)	Final Flow (l/min)	Nominal Flow (l/min)	Pump Run Time (min)	Sample Weight (mg)	Conc, (mg/m^3)	Correction Factor	Corrected Conc, (mg/m^3)
3-1	37 mm F.G.	68.55	69.22	0.01	d-1	c-1	1.94	1.99	1.90	62	0.66	5.60	1	5.60
3-2	37 mm F.G.	68.09	68.80	0.01	d-2	c-2	1.93	1.95	1.90	62	0.70	5.94	1	5.94
3-3	37 mm F.G.	69.66	70.29	0.01	d-3	c-3	1.92	1.97	1.90	62	0.62	5.26	1	5.26
3-4	37 mm F.G.	68.74	69.37	0.01	d-4	c-4	1.90	1.92	1.90	62	0.62	5.26	1	5.26
3-5	37 mm F.G.	69.65	70.31	0.01	d-5	c-5	1.94	1.93	1.90	62	0.65	5.52	1	5.52
3-6	37 mm F.G.	71.25	71.91	0.01	d-6	c-6	1.92	1.91	1.90	62	0.65	5.52	1	5.52
3-7	37 mm F.G.	69.44	70.07	0.01	d-7	c-7	1.90	1.94	1.90	62	0.62	5.26	1	5.26
3-8	37 mm F.G.	69.80	70.41	0.01	d-8,	c-8	1.95	1.95	1.90	62	0.60	5.09	1	5.09
3-9	37 mm F.G.	69.95	70.60	0.01	d-9	c-9	1.92	1.91	1.90	62	0.64	5.43	1	5.43
3-10	37 mm F.G.	70.22	70.76	0.01	d-10	c-10	1.88	1.88	1.90	62	0.53	4.50	1	4.50
3-11	37 mm F.G.	70.31	70.91	0.01	d-11	c-11	1.89	1.90	1.90	62	0.59	5.01	1	5.01
3-12	37 mm F.G.	70.46	71.10	0.01	d-12	c-12	1.95	1.94	1.90	62	0.63	5.35	1	5.35
3-13	37 mm F.G.	70.82	71.46	0.01	g-1	c-13	1.90	1.90	1.90	62	0.63	5.35	1	5.35
3-14	37 mm F.G.	69.49	70.23	0.01	g-23	c-14	1.90	1.90	1.90	62	0.73	6.20	1	6.20
3-15	37 mm F.G.	68.69	69.34	0.01	g-24	c-15	1.90	1.90	1.90	62	0.64	5.43	1	5.43
3-16	37 mm F.G.	69.76	70.39	0.01	g-6	c-16	1.90	1.90	1.90	62	0.62	5.26	1	5.26
3-17	37 mm F.G.	69.98	70.66	0.01	g-5	c-17	1.90	1.90	1.90	62	0.67	5.69	1	5.69
3-18	37 mm F.G.	70.78	70.72	0.01	g-4	c-18	1.90	1.90	1.90	62	-0.07	-0.59	1	-0.59
3-19	55 mm F.G.	622.39	623.15	0.01	Cas 3949	Cas 3949	2.56	2.56	2.56	63	0.75	4.65	1	4.65
3-20	55 mm F.G.	637.63	638.41	0.01	Cas 3928	Cas 3928	2.50	2.50	2.50	63	0.77	4.89	1	4.89
3-21	47 mm F.G.	90.64	90.85	0.01	SIMSLIN SIMSLIN SIMSLIN	SIMSLIN L.S.(SIM) L.S.(CHART)	0.625	0.625	0.625	63 63 63	0.20	5.12 4.2		5.27 4.3 4.36
3-22	55 mm F.G.	3091.64	3107.97	0.01	g-12	Hex A	50.00	50.00	50.00	62	16.32	5.26	1	5.26
3-23	55 mm F.G.	3037.99	3041.48	0.01	g-15	Hex B	50.00	50.00	50.00	62	3.48	1.12	1	1.12

Table 5 - Trial No. 4

Filter Number	Filter Type	Initial Weight (mg)	Final Weight (mg)	Blank Change	Pump # Gauge #	Holder # or Type	Initial Flow (l/min)	Final Flow (l/min)	Nominal Flow (l/min)	Pump Run Time (min)	Sample Weight (mg)	Conc. (mg/m^3)	Correction Factor	Corrected Conc. (mg/m^3)
4-1	37 mm F.G.	70.55	72.13	-0.01	d-1	c-1	1.90	1.90	1.900	52	1.59	16.09	0.98923	15.92
4-2	37 mm F.G.	71.68	73.34	-0.01	d-2	c-2	1.95	1.92	1.900	52	1.67	16.90	0.98923	16.72
4-3	37 mm F.G.	71.14	72.64	-0.01	d-3	c-3	1.97	1.91	1.900	52	1.51	15.28	0.98923	15.12
4-4	37 mm F.G.	70.81	72.36	-0.01	d-4	c-4	1.92	1.89	1.900	52	1.56	15.79	0.98923	15.62
4-5	37 mm F.G.	70.15	71.82	-0.01	d-5	c-5	1.93	1.90	1.900	52	1.68	17.00	0.98923	16.82
4-6	37 mm F.G.	71.29	72.92	-0.01	d-6	c-6	1.91	1.88	1.900	52	1.64	16.60	0.98923	16.42
4-7	37 mm F.G.	71.21	72.74	-0.01	d-7	c-7	1.94	1.91	1.900	52	1.54	15.59	0.98923	15.42
4-8	37 mm F.G.	70.38	72.01	-0.01	d-8	c-8	1.95	1.91	1.900	52	1.64	16.60	0.98923	16.42
4-9	37 mm F.G.	71.33	73.02	-0.01	d-9	c-9	1.91	1.87	1.900	52	1.70	17.21	0.98923	17.02
4-10	37 mm F.G.	71.83	73.42	-0.01	d-10	c-10	1.88	1.83	1.900	52	1.60	16.19	0.98923	16.02
4-11	37 mm F.G.	72.40	73.96	-0.01	d-11	c-11	1.90	1.83	1.900	52	1.57	15.89	0.98923	15.72
4-12	37 mm F.G.	71.19	72.79	-0.01	d-12	c-12	1.94	1.89	1.900	52	1.61	16.30	0.98923	16.12
4-13	37 mm F.G.	71.43	73.11	-0.01	g-22	c-13	1.90	1.90	1.900	52	1.69	17.11	0.98923	16.92
4-14	37 mm F.G.	71.33	72.92	-0.01	g-23	c-14	1.90	1.90	1.900	52	1.60	16.19	0.98923	16.02
4-15	37 mm F.G.	77.34	79.02	-0.01	g-24	c-15	1.90	1.90	1.900	52	1.69	17.11	0.98923	16.92
4-16	37 mm F.G.	77.28	79.00	-0.01	g-25	c-16	1.90	1.90	1.900	52	1.73	17.51	0.98923	17.32
4-17	37 mm F.G.	74.58	76.32	-0.01	g-5	c-17	1.90	1.90	1.900	52	1.75	17.71	0.98923	17.52
4-18	37 mm F.G.	73.58	73.58	-0.01	g-?	c-18	1.90	1.90	1.900	52	0.01	0.10	0.98923	0.10
4-19	37 mm F.G.	77.62	78.42	-0.01	g-1	N1	2.00	2.00	2.000	52	0.81	7.79	0.98923	7.70
4-20	37 mm F.G.	75.09	76.64	-0.01	g-4	N2	2.00	2.00	2.000	52	0.56	5.38	0.98923	5.33
4-21	37 mm F.G.	77.66	78.33	-0.01	g-6	N3	2.00	2.00	2.000	52	0.68	6.54	0.98923	6.47
4-22	37 mm F.G.	74.95	75.72	-0.01	g-9	N4	2.00	2.00	2.000	52	0.78	7.50	0.98923	7.42
4-23	37 mm F.G.	76.81	77.58	-0.01	g-26	N5	2.00	2.00	2.000	52	0.78	7.50	0.98923	7.42
4-24	55 mm F.G.	625.45	627.27	-0.01	Cas 3949	Cas 3949	2.51	2.51	2.510	54	1.83	13.50	1.00000	13.50
4-25	55 mm F.G.	622.98	624.93	-0.01	Cas 3928	Cas 3928	2.49	2.48	2.485	54	1.96	14.61	1.00000	14.61
4-27	55 mm F.G.	3103.95	3142.24	-0.01	g-12	Hex A	50.00	50.00	50.000	52	38.30	14.73	0.98923	14.57
4-26	47 mm F.G.	89.95	90.52	-0.01	SIMSLIN	SIMSLIN	0.625	0.625	0.625	62	0.58	15.09		16.26
					SIMSLIN	L.S.(SIM)				62		10.3		11.1
					SIMSLIN	L.S. (CHART)				62				10.98
4-45	55 mm F.G.	3124.91	3162.89	-0.01	g-15	Hex B	50.00	50.00	50.000	52	37.99	14.61	0.98923	14.45
4-1312	25 mm S.M.	134.15	135.06	-0.01	g-7	R-1	1.70	1.70	1.700	52	0.92	10.41	0.98923	10.30
4-1313	25 mm S.M.	129.66	130.53	-0.01	g-21	E-1	1.70	1.70	1.700	52	0.88	9.95	0.98923	9.85

Table 6 - Trial No. 5

Filter Number	Filter Type	Initial Weight (mg)	Final Weight (mg)	Blank Change	Pump # Gauge #	Holder # or Type	Initial Flow (l/min)	Final Flow (l/min)	Nominal Flow (l/min)	Pump Run Time (min)	Sample Weight (mg)	Conc. (mg/m^3)	Correction Factor	Corrected Conc. (mg/m^3)
5-1	37 mm S.M.	305.89	306.42	-0.01	d-1	c-1	1.90	1.90	1.900	77	0.54	3.69		
5-2	37 mm S.M.	323.97	324.50	-0.01	d-2	c-2	1.95	1.92	1.900	77	0.54	3.69		
5-3	37 mm S.M.	303.50	304.00	-0.01	d-3	c-3	1.97	1.91	1.900	77	0.51	3.49		
5-4	37 mm S.M.	280.30	280.83	-0.01	d-4	c-4	1.92	1.89	1.900	77	0.54	3.69		
5-5	37 mm S.M.	273.86	274.40	-0.01	d-5	c-5	1.93	1.90	1.900	77	0.55	3.76		
5-6	37 mm S.M.	336.23	336.75	-0.01	d-6	c-6	1.91	1.88	1.900	77	0.53	3.62		
5-7	37 mm F.G.	69.58	70.07	0.01	d-7	c-7	1.94	1.91	1.900	77	0.48	3.28		
5-8	37 mm F.G.	70.16	70.66	0.01	d-8	c-8	1.95	1.91	1.900	75	0.49	3.44		
5-9	37 mm F.G.	70.31	70.79	0.01	d-9	c-9	1.91	1.87	1.900	77	0.47	3.21		
5-10	37 mm F.G.	71.03	71.53	0.01	d-10	c-10	1.88	1.83	1.900	77	0.49	3.35		
5-11	37 mm F.G.	70.36	70.83	0.01	d-11	c-11	1.90	1.83	1.900	77	0.46	3.14		
5-12	37 mm F.G.	71.80	72.32	0.01	d-12	c-12	1.94	1.89	1.900	77	0.51	3.49		
5-13	37 mm F.G.	71.25	71.82	0.01	g-?	c-13	1.90	1.90	1.900	77	0.56	3.83		
5-14	37 mm F.G.	71.25	71.77	0.01	g-23	c-14	1.90	1.90	1.900	77	0.51	3.49		
5-15	37 mm F.G.	69.16	69.71	0.01	g-24	c-15	1.90	1.90	1.900	77	0.54	3.69		
5-16	37 mm F.G.	70.94	71.47	0.01	g-6	c-16	1.90	1.90	1.900	77	0.52	3.55		
5-17	37 mm F.G.	73.58	74.14	0.01	g-5	c-18	1.90	1.90	1.900	77	0.55	3.76		
5-18	37 mm F.G.	71.41	71.59	0.01	g-?	N1	2.00	2.00	2.000	77	0.17	1.10		
5-19	37 mm F.G.	70.75	70.87	0.01	g-?	N2	2.00	2.00	2.000	77	0.11	0.71		
5-20	37 mm F.G.	70.29	70.41	0.01	g-?	N3	2.00	2.00	2.000	77	0.11	0.71		
5-21	55 mm F.G.	644.35	644.93	0.01	Cas 3949	Cas 3949	2.49	2.48	2.485	82	0.57	2.80	1	2.80
5-22	55 mm F.G.	628.75	629.42	0.01	Cas 3928	Cas 3928	2.51	2.51	2.510	82	0.66	3.21	1	3.21
5-23	47 mm S.M.	90.45	90.65	0.01	SIMSLIN SIMSLIN SIMSLIN	SIMSLIN L.S.(SIM) L.S. (CHART)	0.625	0.625	0.625	85 85 85	0.19	3.61 2.3		3.61 2.3
5-24	55 mm F.G.	3127.62	3140.39	0.01	g-12	Hex A	50.00	50.00	50.000	77	12.76	3.31		
5-25	55 mm F.G.	2987.62	3000.67	0.01	g-15	Hex B	50.00	50.00	50.000	77	13.04	3.39		
5-1314	25 mm S.M.	129.44	129.80	-0.01	g-7	R-1	1.70	1.70	1.700	77	0.37	2.83		
5-1315	25 mm S.M.	118.38	118.70	-0.01	g-21	E-1	1.70	1.70	1.700	77	0.33	2.52		
5-1316	25 mm S.M.	121.18	121.72	-0.01	g-4	CAMPED 5/33	2.00	2.00	2.000	77	0.55	4.20		
5-1317	25 mm S.M.	125.99	126.51	-0.01	g-1	CAMPED 6/26	2.00	2.00	2.000	77	0.53	4.05		

Table 7 - Trial No. 6

Filter Number	Filter Type	Initial Weight (mg)	Final Weight (mg)	Blank Change	Pump # Gauge #	Holder # or Type	Initial Flow (l/min)	Final Flow (l/min)	Nominal Flow (l/min)	Pump Run Time (min)	Sample Weight (mg)	Conc. (mg/m^3)	Correction Factor	Corrected Conc. (mg/m^3)
6-1	37 mm M.P.	37.55	37.94	0.04	d-1	c-1	1.90	1.89	1.90	118	0.35	1.56	1	1.56
6-2	37 mm M.P.	37.84	38.27	0.04	d-2	c-2	1.92	1.89	1.90	118	0.39	1.74	1	1.74
6-3	37 mm M.P.	37.98	38.40	0.04	d-3	c-3	1.91	1.88	1.90	118	0.38	1.69	1	1.69
6-4	37 mm M.P.	37.71	38.09	0.04	d-4	c-4	1.89	1.90	1.90	118	0.34	1.52	1	1.52
6-5	37 mm M.P.	39.02	39.47	0.04	d-5	c-5	1.90	1.89	1.90	118	0.41	1.83	1	1.83
6-6	37 mm M.P.	40.97	41.38	0.04	d-6	c-6	1.88	1.87	1.90	118	0.37	1.65	1	1.65
6-7	37 mm S.M.	349.63	350.00	0.01	d-7	c-7	1.91	1.91	1.90	118	0.36	1.61	1	1.61
6-8	37 mm S.M.	357.31	357.69	0.01	d-8	c-8	1.91	1.90	1.90	118	0.37	1.65	1	1.65
6-9	37 mm S.M.	366.93	367.34	0.01	d-9	c-9	1.87	1.85	1.90	118	0.40	1.78	1	1.78
6-10	37 mm S.M.	365.03	365.37	0.01	d-10	c-10	1.88	1.89	1.90	118	0.33	1.47	1	1.47
6-11	37 mm S.M.	368.82	369.07	0.01	d-11	c-11	1.90	1.89	1.90	118	0.24	1.07	1	1.07
6-12	37 mm S.M.	348.94	349.29	0.01	d-12	c-12	1.90	1.90	1.90	118	0.34	1.52	1	1.52
6-13	55 mm F.G.	621.92	622.43	0.01	Cas 3949	Cas 3949	2.51	2.51	2.51	116	0.50	1.72	1	1.72
6-14	55 mm F.G.	627.38	627.91	0.01	Cas 3928	Cas 3928	2.48	2.48	2.48	116	0.52	1.81	1	1.81
6-15	55 mm F.G.	3047.30	3056.30	0.01	g-12	Hex A	50.00	50.00	50.00	118	8.99	1.52	1	1.52
6-16	55 mm F.G.	3087.30	3096.36	0.01	g-15	Hex B	50.00	50.00	50.00	118	9.05	1.53	1	1.53
6-1318	25 mm S.M.	123.80	123.98	0.01	g-7	R-1	1.70	1.70	1.70	118	0.17	0.85	1	0.85
6-1319	25 mm S.M.	140.98	141.20	0.01	g-2	E-1	1.70	1.70	1.70	118	0.21	1.05	1	1.05
6-1320	25 mm S.M.	114.45	114.73	0.01	g-4	CAMPED 5/33	2.00	2.00	2.00	118	0.27	1.14	1	1.14
6-1321	25 mm S.M.	122.79	123.08	0.01	g-1	CAMPED 6/26	2.00	2.00	2.00	118	0.28	1.19	1	1.19
6-21	47 mm F.G.	89.08	89.20	0.01	SIMSLIN	SIMSLIN	0.625	0.625	0.625	118	0.11	1.50		1.56
					SIMSLIN	L.S.(SIM)				118		2.1		2.2
					SIMSLIN	L.S. (CHART)				118				2.10

from the SIMSLIN light-scattering charts (Appendix A, compressed graphs) and deriving a correction factor (see Tables 2 to 7). Since the SIMSLIN was the first instrument to be turned on and the last to be turned off in all cases, and since the dust concentration is relatively proportional to the SIMSLIN chart results, then the procedure used for deriving this correction factor is valid. Correction factors, if any, are typically very close to unity, thus corrected concentrations vary little from the uncorrected concentrations. (Note: There is no SIMSLIN light-scattering chart for Test No. 5.)

Table 8 lists all the corrected concentrations for each sampling system for the six trials. Also included are the means and sample standard deviations for each trial of the BMRC cyclones and the means for each trial of the Casella Type 113A and Hexhlet.

SAMPLING SYSTEMS VS CASELLA TYPE 113A AVERAGE

Table 9 presents the results of linear regressions performed for each sampling system versus the Casella Type 113A average for the first five trials. Also included are the Pearson product-moment correlation coefficient (r) and the standard error of estimate for each sampling system. Graphs showing the plotted points, best fit lines and lines of equality are presented in Appendix B. (For comparison purposes silica results from Trial 6 are also included on the graphs.)

SAMPLING SYSTEMS VS HEXHLET AVERAGE

Table 10 presents the results of linear regressions performed for each sampling system versus the Hexhlet average for the first five trials. Also included are the Pearson product-moment correlation coefficient (r) and the standard error of estimate for each sampling system. Graphs showing the plotted points, best fit lines and lines of equality are presented in Appendix C. (For comparison purposes silica results from Trial 6 are also included on the graphs.)

BMRC CASELLA CYCLONES VS CASELLA TYPE 113A AVERAGE

Table 11 presents the results of linear regressions performed for each BMRC Casella cyclone (1 through 18) versus the Casella gravimetric sampler Type 113A average for the first five trials. Also included are the Pearson product-moment correlation coefficient (r) and the standard error of

Table 8 - Respirable dust concentrations for Trials 1 through 6

Sampler	Trial 1 Conc, (mg/m^3)	Trial 2 Conc, (mg/m^3)	Trial 3 Conc, (mg/m^3)	Trial 4 Conc, (mg/m^3)	Trial 5 Conc, (mg/m^3)	Trial 6 Conc, (mg/m^3)
BMRC Cyclone No. 1	4.23	9.43	5.60	15.92	3.69	1.56
BMRC Cyclone No. 2	4.36	10.82	5.94	16.72	3.69	1.74
BMRC Cyclone No. 3	4.23	10.39	5.26	15.12	3.49	1.69
BMRC Cyclone No. 4	4.13	10.18	5.26	15.62	3.69	1.52
BMRC Cyclone No. 5	4.53	9.96	5.52	16.82	3.76	1.83
BMRC Cyclone No. 6	4.20	10.71	5.52	16.42	3.62	1.65
BMRC Cyclone No. 7	5.15	10.28	5.26	15.42	3.28	1.61
BMRC Cyclone No. 8	5.19	10.39	5.09	16.42	3.44	1.65
BMRC Cyclone No. 9	5.05	10.18	5.43	17.02	3.21	1.78
BMRC Cyclone No. 10	5.09	10.39	4.50	16.02	3.35	1.47
BMRC Cyclone No. 11	3.80	10.07	5.01	15.72	3.14	1.07
BMRC Cyclone No. 12	4.36	10.71	5.35	16.12	3.49	1.52
BMRC Cyclone No. 13	4.62	10.84	5.35	16.92	3.88	
BMRC Cyclone No. 14	4.86	10.84	6.20	16.02	3.49	
BMRC Cyclone No. 15	4.39	11.05	5.43	16.92	3.69	
BMRC Cyclone No. 16	4.89	11.16	5.26	17.32	3.55	
BMRC Cyclone No. 17	5.02	11.26	5.69	17.52	-	
BMRC Cyclone No. 18	4.20	9.47	-	-	3.76	
Casella Type 113A 3949	3.87	7.97	4.65	13.50	2.80	1.72
Casella Type 113A 3928	4.15	8.56	4.89	14.61	3.21	1.81
Hexhlet A	3.43	9.54	5.26	14.47	3.31	1.52
Hexhlet B	3.08	9.77	-	14.45	3.39	1.53
(25 mm) Nylon Cyclone E-1	2.51	6.59		9.85	2.52	1.05
(25 mm) Nylon Cyclone E-3	2.55	6.47				
(25 mm) Nylon Cyclone R-1	2.36	6.82		10.30	2.83	0.85

Table 8 - (cont'd)

Sampler	Trial 1 Conc. (mg/m^3)	Trial 2 Conc. (mg/m^3)	Trial 3 Conc. (mg/m^3)	Trial 4 Conc. (mg/m^3)	Trial 5 Conc. (mg/m^3)	Trial 6 Conc. (mg/m^3)
(25 mm) Nylon Cyclone R-2	2.55	7.06				
(25 mm) Nylon Cyclone E-2	2.77	6.59				
CAMPEDS 5/33	3.33	9.70			4.20	1.14
CAMPEDS 6/26	3.42	9.30			4.05	1.19
SIMSLIN Gravimetric	6.40	4.61	5.27	16.26	3.61	1.56
SIMSLIN Light-Scattering	2.80	-	4.30	11.10	2.30	2.20
SIMSLIN Light-Scattering (Chart)	2.87	6.66	4.36	10.98	-	2.10
(37 mm) Nylon Cyclone N1				7.70	1.10	
(37 mm) Nylon Cyclone N2				5.33	0.71	
(37 mm) Nylon Cyclone N3				6.47	0.71	
(37 mm) Nylon Cyclone N4				7.42		
(37 mm) Nylon Cyclone N5				7.42		
BMRC Cyclone Average	4.57	10.45	5.39	16.36	3.54	1.59
Sample Standard Deviation	0.42	0.52	0.37	0.69	0.21	0.20
Casella Type 113A Average	4.01	8.27	4.77	14.06	3.01	1.77
Hexhlet Average	3.26	9.66	5.26	14.46	3.35	1.53

Table 9 - Various sampling systems vs Casella Type 113A average

Sampling System	A0	A1	# of data pairs used to determine equation	r	r^2	Standard Error of Estimate
BMRC Cyclones	0.111	0.832	87	.9926	.9853	0.490
Hexhlet	0.229	0.921	9	.9886	.9773	0.713
SIMSLIN Gravimetric	1.252	0.771	5	.8810	.7762	2.460
SIMSLIN Light-Scattering	0.045	1.248	5	.9958	.9916	0.475
(37 mm) Nylon Cyclones	1.930	1.733	8	.9724	.9455	1.442
(25 mm) Nylon Cyclones	0.222	1.288	14	.9832	.9667	0.714
CAMPEDS	0.570	0.799	6	.9565	.9149	0.815

$$Y = A0 + A1 \cdot x$$

where x = concentration (mg/m^3) obtained using a particular sampling system (e.g. BMRC cyclones or SIMSLIN light-scattering).

Y = concentration (mg/m^3) corrected to MRE equivalent concentration or to the Casella Type 113A basis.

r = Pearson product-moment correlation coefficient - this is a measure of how closely the line fits the data points. When r approaches ±1.0 there is good correlation.

Table 10 - Various sampling systems vs Hexhlet average

Sampling System	A0	A1	# of data pairs used to determine equation	r	r^2	Standard Error of Estimate
BMRC Cyclones	0.014	0.890	87	.9897	.9795	0.622
Casella Type 113A	0.021	1.052	10	.9861	.9724	0.802
SIMSLIN Gravimetric	1.735	0.756	5	.8074	.6519	3.283
SIMSLIN Light-Scattering	-0.037	1.332	5	.9933	.9866	0.644
(37 mm) Nylon Cyclones	2.265	1.743	8	.9724	.9455	1.450
(25 mm) Nylon Cyclones	-0.541	1.502	14	.9976	.9951	0.314
CAMPEDS	-0.756	1.090	6	.9939	.9879	0.404

$$Y = A0 + A1 \cdot x$$

where x = concentration (mg/m^3) obtained using a particular sampling system (e.g. BMRC cyclones or SIMSLIN light-scattering).

Y = concentration (mg/m^3) corrected to the Hexhlet basis or the concentration which would be measured if a Hexhlet sampler were used.

r = Pearson product-moment correlation coefficient - this is a measure of how closely the line fits the data points. When r approaches ±1.0 there is good correlation.

Table 11 - BMRC cyclones vs Casella gravimetric sampler Type 113A average

BMRC Cyclone Number	A0	A1	# of data pairs used to determine equation	r	r^2	Standard Error of Estimate
1	-0.067	0.886	5	.9990	.9980	0.672
2	0.011	0.820	5	.9958	.9916	0.349
3	-0.120	0.902	5	.9915	.9830	0.444
4	-0.023	0.881	5	.9951	.9903	0.406
5	0.088	0.830	5	.9995	.9990	0.729
6	0.146	0.825	5	.9949	.9899	0.366
7	-0.295	0.904	5	.9936	.9872	0.897
8	0.005	0.841	5	.9959	.9919	0.941
9	0.222	0.807	5	.9988	.9977	0.927
10	0.194	0.842	5	.9911	.9823	1.056
11	0.458	0.843	5	.9956	.9911	0.407
12	0.106	0.839	5	.9941	.9883	0.478
13	0.079	0.811	5	.9961	.9922	0.592
14	-0.393	0.871	5	.9934	.9868	0.563
15	0.219	0.796	5	.9947	.9894	0.466
16	0.262	0.778	5	.9955	.9909	0.724
17	0.032	0.785	4	.9959	.9919	0.766
18	0.020	0.874	3	.9939	.9878	0.423

estimate for each cyclone. Graphs showing the plotted points, best fit lines and lines of equality are presented in Appendix D. (For comparison purposes silica results from Trial 6 are also included on the graphs.)

BMRC CASELLA CYCLONES VS HEXHLET AVERAGE

Table 12 presents the results of linear regressions performed for each BMRC Casella cyclone (1 through 18) versus the Hexhlet average for the first five trials. Also included are the Pearson product-moment correlation coefficient (r) and the standard error of estimate for each cyclone. Graphs showing the plotted points, best fit lines and lines of equality are presented in Appendix E. (For comparison purposes silica results from Trial 6 are also included on the graphs.)

COMPARATIVE TESTS OF BMRC CASELLA CYCLONES

Figure 1 presents a graph of the concentration results of the BMRC Casella cyclones versus the cyclone number. Table 13 presents the z-score transformations for all the BMRC Casella cyclones for the six trials. Each case (in the table) contains a value equivalent to the number of standard deviation units it is above or below the mean. Thus, by comparing the z-score variables of a particular cyclone we can tell whether that particular cyclone tends to collect dust more or less efficiently than the others (e.g. if the z-scores for a particular cyclone were all negative then it may indicate that this particular cyclone is reading consistently low).

Note: The z-score transformation variables in Table 13 are actually calculated using the "t" distribution formula which uses sample standard deviation rather than population standard deviation:

$$\text{z-score (t)} = (x_i - \bar{x})/SD_s$$

where x_i = the original value of the ith case in the table for the variable being transformed.

$\bar{x}$ = the mean of the variable and

SD_s = the sample standard deviation calculated by the formula

$$SD_s^2 = \sum_{i=1}^{n} (x_i - \bar{x})^2/(n-1)$$

Table 12 - BMRC cyclones vs Hexhlet gravimetric sampler average

BMRC Cyclone Number	A0	A1	# of data pairs used to determine equation	r	r^2	Standard Error of Estimate
1	-0.127	0.942	5	.9927	.9854	0.232
2	-0.107	0.879	5	.9980	.9961	0.477
3	-0.271	0.970	5	.9968	.9936	0.678
4	-0.144	0.944	5	.9973	.9947	0.513
5	0.050	0.880	5	.9914	.9828	0.167
6	0.032	0.885	5	.9978	.9957	0.523
7	-0.367	0.960	5	.9869	.9740	0.588
8	-0.022	0.891	5	.9856	.9714	0.469
9	0.225	0.853	5	.9860	.9723	0.250
10	0.171	0.893	5	.9818	.9640	0.691
11	0.375	0.904	5	.9973	.9946	0.490
12	0.106	0.839	5	.9941	.9926	0.563
13	-0.006	0.866	5	.9943	.9887	0.459
14	-0.535	0.934	5	.9949	.9898	0.598
15	0.119	0.853	5	.9965	.9930	0.534
16	0.205	0.829	5	.9915	.9831	0.495
17	-0.225	0.849	4	.9921	.9842	0.506
18	-1.264	1.151	3	.9967	.9934	0.436

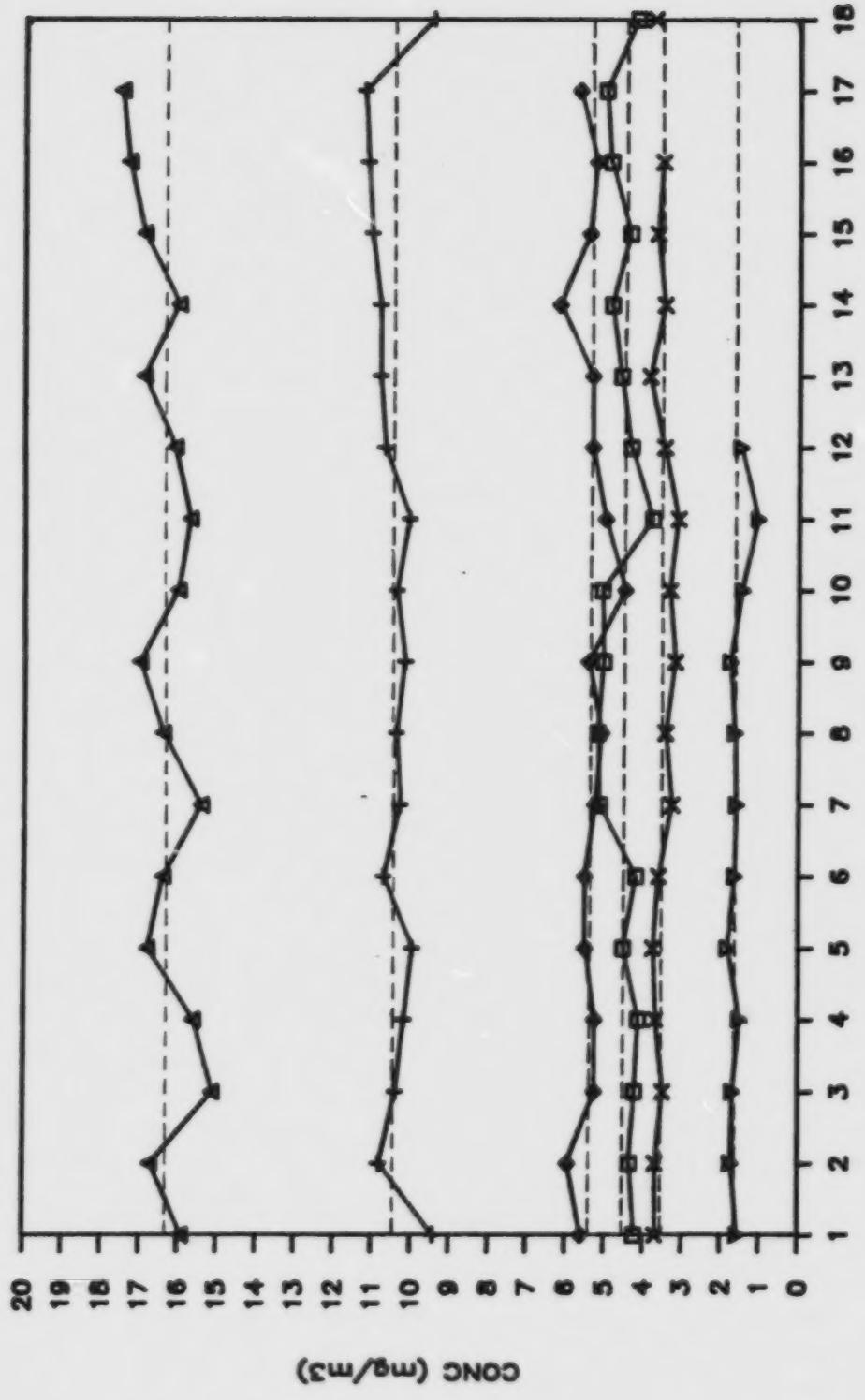


Figure 1 - Respirable dust concentration (BMRC cyclone) vs BMRC cyclone No.

Table 13 - Z-score transformations for BMRC cyclones

BMRC Cyclone Number	Test 1	Test 2	Test 3	Test 4	Test 5	Test 6
1	-0.81	-1.95	0.56	-0.63	0.71	-0.16
2	-0.50	0.70	1.47	0.53	0.71	0.76
3	-0.81	-0.12	-0.35	-1.80	-0.25	0.50
4	-1.05	-0.52	-0.35	-1.07	0.71	-0.36
5	-0.10	-0.94	0.34	0.68	1.04	1.21
6	-0.88	0.49	0.34	0.09	0.37	0.30
7	1.37	-0.33	-0.35	-1.36	-1.26	0.10
8	1.46	-0.12	-0.81	0.09	-0.49	0.30
9	1.13	-0.52	0.10	0.97	-1.59	0.96
10	1.23	-0.12	-2.39	-0.49	-0.92	-0.61
11	-1.83	-0.73	-1.02	-0.93	-1.93	-2.64
12	-0.50	0.49	-0.11	-0.34	-0.25	-0.36
13	0.11	0.74	-0.11	0.82	1.62	-
14	0.68	0.74	2.16	-0.49	-0.25	-
15	-0.43	1.14	0.10	0.82	0.71	-
16	0.75	1.35	-0.35	1.41	0.04	-
17	1.06	1.54	0.80	1.70	-	-
18	-0.88	-1.87	-	-	1.04	-

However, since we are looking only at the comparative trends of the BMRC Casella cyclones, the values are reported as z-scores.

Figure 2 plots the sample standard deviation for each trial versus the average concentration of the BMRC Casella cyclones.

CONVERSION OF SAMPLING SYSTEM RESULTS TO CASELLA GRAVIMETRIC SAMPLER TYPE 113A BASIS AND HEXHLET BASIS

Table 14 presents the respirable dust concentration results for the first five trials calculated to the Casella Type 113A basis using the appropriate equations from Table 9 (MRE equivalent concentrations).

Table 15 presents the respirable dust concentration results for the first five trials calculated to the Hexhlet basis using the appropriate equations from Table 10.

DISCUSSIONS

The following are some observations and interpretations pertaining to the respirable dust results of the six trials:

1a) The first five trials were performed using a range of coal dust concentrations, whereas silica dust was used for the sixth trial. Since silica dust does not necessarily behave the same as coal dust, results from Trial No. 6 were not used in the calculation of the linear regression equations. Respirable silica results are, however, included on the graphs for comparison purposes.

1b) For Trial No. 6, 37 mm millipore filters were used with the BMRC cyclones 1 to 6 and 37 mm silver membrane filters were used with the remaining cyclones 7 to 12 (see Table 7). There appeared to be no significant difference in the calculated respirable dust measurements between these two filter types for these trials.

1c) It is not possible to come up with any conclusive statements concerning the results using silica dust as there was only one trial with a relatively low dust concentration. However, for that particular trial, the silica dust did seem to behave similarly to the coal dust for the gravimetric determinations (same separation characteristics), but not for the light-scattering determinations.

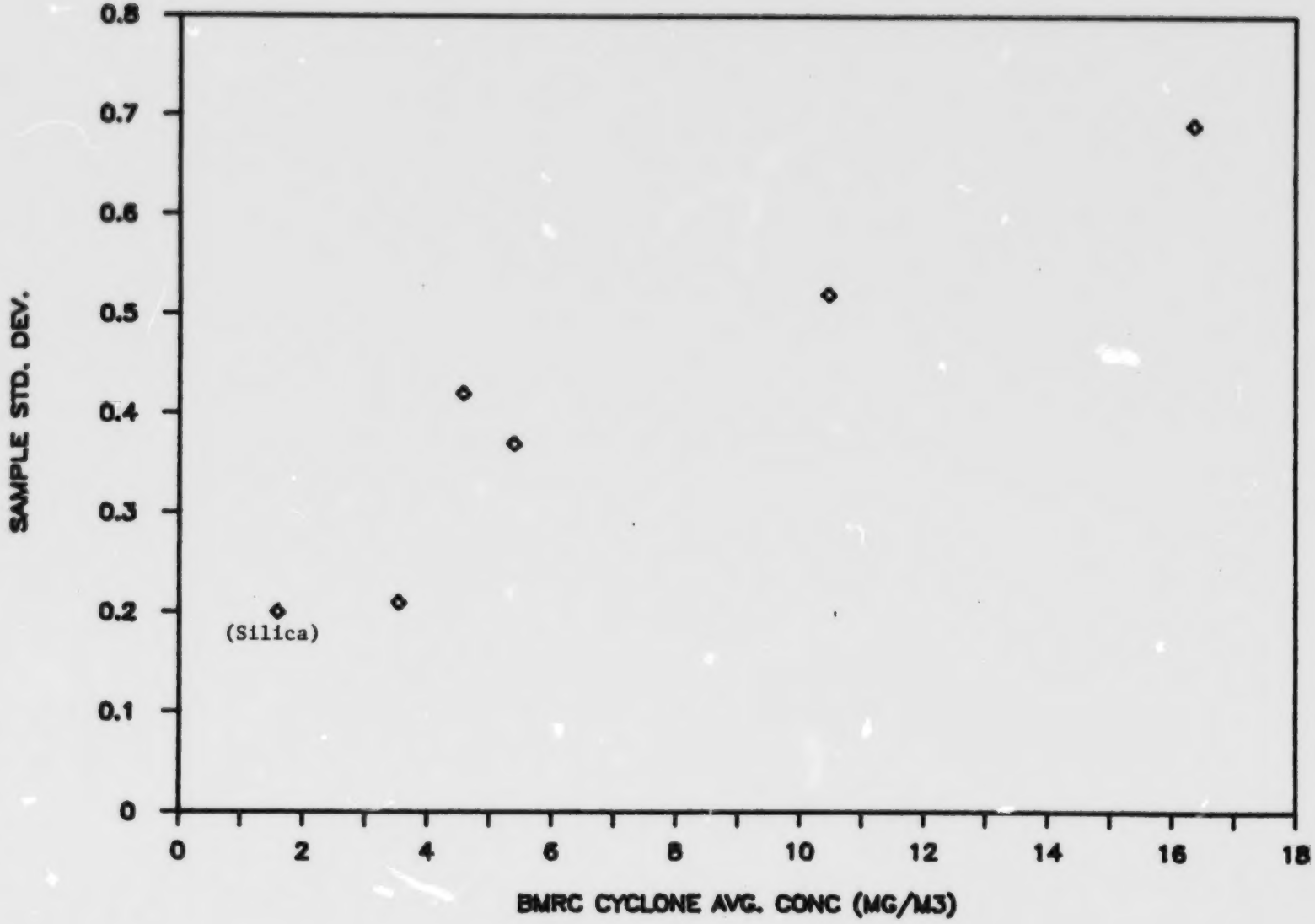


Figure 2 - Sample standard deviation vs average concentration of BMRC cyclones

Table 14 - Respirable dust measurements calculated to Casella Type 113A basis

Sampler	Trial 1 Conc, (mg/m^3)	Trial 2 Conc, (mg/m^3)	Trial 3 Conc, (mg/m^3)	Trial 4 Conc, (mg/m^3)	Trial 5 Conc, (mg/m^3)
BMRC Cyclone No. 1	3.63	7.96	4.77	13.36	3.18
BMRC Cyclone No. 2	3.74	9.11	5.05	14.02	3.18
BMRC Cyclone No. 3	3.63	8.75	4.49	12.69	3.01
BMRC Cyclone No. 4	3.55	8.58	4.49	13.11	3.18
BMRC Cyclone No. 5	3.88	8.40	4.70	14.10	3.24
BMRC Cyclone No. 6	3.61	9.02	4.70	13.77	3.12
BMRC Cyclone No. 7	4.40	8.66	4.49	12.94	2.84
BMRC Cyclone No. 8	4.43	8.75	4.35	13.77	2.97
BMRC Cyclone No. 9	4.31	8.58	4.63	14.27	2.78
BMRC Cyclone No. 10	4.35	8.75	3.86	13.44	2.90
BMRC Cyclone No. 11	3.27	8.49	4.28	13.19	2.72
BMRC Cyclone No. 12	3.74	9.02	4.56	13.52	3.01
BMRC Cyclone No. 13	3.96	9.13	4.56	14.19	3.34
BMRC Cyclone No. 14	4.15	9.13	5.27	13.44	3.01
BMRC Cyclone No. 15	3.76	9.30	4.63	14.19	3.18
BMRC Cyclone No. 16	4.18	9.40	4.49	14.52	3.06
BMRC Cyclone No. 17	4.29	9.48	4.84	14.69	-
BMRC Cyclone No. 18	3.61	7.99	-	-	3.24
Casella Type 113A 3949	3.87	7.97	4.65	13.50	2.80
Casella Type 113A 3928	4.15	8.56	4.89	14.61	3.21
Hexhlet A	3.39	9.02	5.07	13.56	3.28
Hexhlet B	3.07	9.23	-	13.54	3.35
(25 mm) Nylon Cyclone E-1	3.45	8.71		12.91	3.47

Table 14 - Cont'd

Sampler	Trial 1 Conc, (mg/m^3)	Trial 2 Conc, (mg/m^3)	Trial 3 Conc, (mg/m^3)	Trial 4 Conc, (mg/m^3)	Trial 5 Conc, (mg/m^3)
(25 mm) Nylon Cyclone E-3	3.51	8.56			
(25 mm) Nylon Cyclone R-1	3.26	9.01		13.49	3.87
(25 mm) Nylon Cyclone R-2	3.51	9.32			
(25 mm) Nylon Cyclone E-2	3.79	8.71			
CAMPEDS 5/33	3.23	8.32			3.93
CAMPEDS 6/26	3.30	8.00			3.81
SIMSLIN Gravimetric	6.19	4.81	5.32	13.79	4.04
SIMSLIN Light-Scattering	3.54	-	5.41	13.90	2.92
SIMSLIN Light-Scattering (Chart)	3.63	8.36	5.49	13.75	-
(37 mm) Nylon Cyclone N1				15.27	3.84
(37 mm) Nylon Cyclone N2				11.17	3.16
(37 mm) Nylon Cyclone N3				13.14	3.16
(37 mm) Nylon Cyclone N4				14.79	
(37 mm) Nylon Cyclone N5				14.79	

Table 15 - Respirable dust measurements calculated to Hexhlet basis

Sampler	Trial 1 Conc. (mg/m^3)	Trial 2 Conc. (mg/m^3)	Trial 3 Conc. (mg/m^3)	Trial 4 Conc. (mg/m^3)	Trial 5 Conc. (mg/m^3)
BMRC Cyclone No. 1	3.78	8.41	5.00	14.18	3.30
BMRC Cyclone No. 2	3.89	9.64	5.30	14.89	3.30
BMRC Cyclone No. 3	3.78	9.26	4.70	13.47	3.12
BMRC Cyclone No. 4	3.69	9.07	4.70	13.92	3.30
BMRC Cyclone No. 5	4.05	8.88	4.93	14.98	3.36
BMRC Cyclone No. 6	3.75	9.55	4.93	14.63	3.24
BMRC Cyclone No. 7	4.60	9.16	4.70	13.74	2.93
BMRC Cyclone No. 8	4.63	9.26	4.54	14.63	3.08
BMRC Cyclone No. 9	4.51	9.07	4.85	15.16	2.87
BMRC Cyclone No. 10	4.54	9.26	4.02	14.27	3.00
BMRC Cyclone No. 11	3.40	8.98	4.47	14.00	2.81
BMRC Cyclone No. 12	3.89	9.55	4.78	14.36	3.12
BMRC Cyclone No. 13	4.13	9.66	4.78	15.07	3.47
BMRC Cyclone No. 14	4.34	9.66	5.53	14.27	3.12
BMRC Cyclone No. 15	3.92	9.85	4.85	15.07	3.30
BMRC Cyclone No. 16	4.37	9.95	4.70	15.43	3.17
BMRC Cyclone No. 17	4.48	10.03	5.08	15.61	-
BMRC Cyclone No. 18	3.75	8.44	-	-	3.36
Casella Type 113A 3949	4.09	8.41	4.91	14.22	2.97
Casella Type 113A 3928	4.39	9.03	5.17	15.39	3.40
Hexhlet A	3.43	9.54	5.26	14.47	3.31
Hexhlet B	3.08	9.77	-	14.45	3.39
(25 mm) Nylon Cyclone E-1	3.23	9.36		14.25	3.24

Table 15 - Cont'd

Sampler	Trial 1 Conc. (mg/m^3)	Trial 2 Conc. (mg/m^3)	Trial 3 Conc. (mg/m^3)	Trial 4 Conc. (mg/m^3)	Trial 5 Conc. (mg/m^3)
(25 mm) Nylon Cyclone E-3	3.29	9.18			
(25 mm) Nylon Cyclone R-1	3.00	9.70		14.93	3.71
(25 mm) Nylon Cyclone R-2	3.29	10.06			
(25 mm) Nylon Cyclone E-2	3.62	9.36			
CAMPEDS 5/33	2.87	9.82			3.82
CAMPEDS 6/26	2.97	9.38			3.66
SIMSLIN Gravimetric	6.57	5.22	5.72	14.03	4.46
SIMSLIN Light-Scattering	3.69	-	5.69	14.75	3.03
SIMSLIN Light-Scattering (Chart)	3.79	8.83	5.77	14.59	-
(37 mm) Nylon Cyclone N1				15.69	4.18
(37 mm) Nylon Cyclone N2				11.56	3.50
(37 mm) Nylon Cyclone N3				13.54	3.50
(37 mm) Nylon Cyclone N4				15.20	
(37 mm) Nylon Cyclone N5				15.20	

The light-scattering determination for the trial using silica dust was proportionally lower than the results using coal dust (see Appendices B and C).

2) The linear regression analyses were done using the respirable dust concentrations from the various sampling systems versus the average concentration of the reference samplers (Casella Type 113A and Hexhlet). Although the results obtained using the reference samplers were generally good, there were nevertheless inherent errors present as evidenced by the difference between duplicate samples (e.g. see results for Casella Type 113A and Hexhlet in Table 8).

3) For the relatively short duration of the tests, the respirable dust concentration results (0-16 mg/m^3) appear to be linear for each of the sampling systems used. This suggests that the efficiency of the dust particle size separation devices, whether they are horizontal elutriators, cyclones or impactors, was unaffected by dust concentration.

4a) Figure 1 and Table 13 present the comparison of the BMRC cyclone respirable dust concentrations versus the cyclone number for Trials 1 through 6. Cyclone No. 11 read lower than the average of all the BMRC cyclones for each of the six trials (negative z-scores). (This implies that this particular cyclone may read consistently low and should be suspect in future trials or surveys.) However, this could perhaps be explained by factors other than the cyclone itself, such as errors associated with reading the pressure gauges, pump flows, uneven dust distribution in the dust chamber or perhaps operator error. Further tests are necessary.

4b) It should be noted that fiberglass filters were used with all the BMRC cyclones in Trials 1 through 4. For Trial No. 5 fiberglass filters were used with cyclone Nos. 7 through 18 but silver membrane filters were used with BMRC cyclone Nos. 1 through 6 (see Table 6). There appeared to be no significant difference between results obtained when using either silver membrane or fiberglass filters for these trials. Consequently, results obtained using silver membrane filters were included with those using fiberglass filters when calculating the linear regression equations.

4c) Figure 2 indicates that the BMRC cyclones are more efficient or consistent when sampling dust above 5 mg/m^3.

5) The sample weights used to determine the SIMSLIN gravimetric results were relatively small. This was mainly due to the lower flow rate of the SIMSLIN (0.625 l/min). This may explain why these results were not as good as those obtained from the other sampling systems (see Tables 9 and 10 and the graphs in Appendices B and C).

CONCLUSION

A dust chamber is a useful apparatus for the comparison of respirable dust sampling systems to both each other and to other sampling systems. Work can be carried out in the relative convenience of the laboratory rather than utilizing more difficult and time consuming field surveys. However, caution must be exercised, for conditions in a dust chamber may not be the same as environmental conditions encountered in actual field surveys (e.g. underground coal mines). For instance, dust produced in underground coal mines is done so in a more random or haphazard fashion from a variety of sources of potentially different mineral make up. As well varying environmental conditons such as temperature, humidity and barometric pressure are normally present in the mines. Consequently, laboratory respirable dust sampling (using a dust chamber) should be complemented by actual field tests.

In summation, the trials at the Elliot Lake Laboratory were an opportunity to compare the various dust monitoring instruments of CBCRL and to gain experience using a dust chamber. It was found that all sampling systems tested, gave both linear and repeatable results which would make them good candidates for routine field work. By using the proper equations or factors, sampling system results could be corrected or calculated to a common basis such as the Casella Type 113A basis (MRE equivalent). Further trials are necessary in order to calculate "better" correction factors or equations for more precise results. (Efforts are underway to have a dust chamber in place at CBCRL sometine in the near future.) The results of these tests will be compared with actual field trials conducted at CBDC's underground coal mines and will be presented in a report at a later date.

ACKNOWLEDGEMENTS

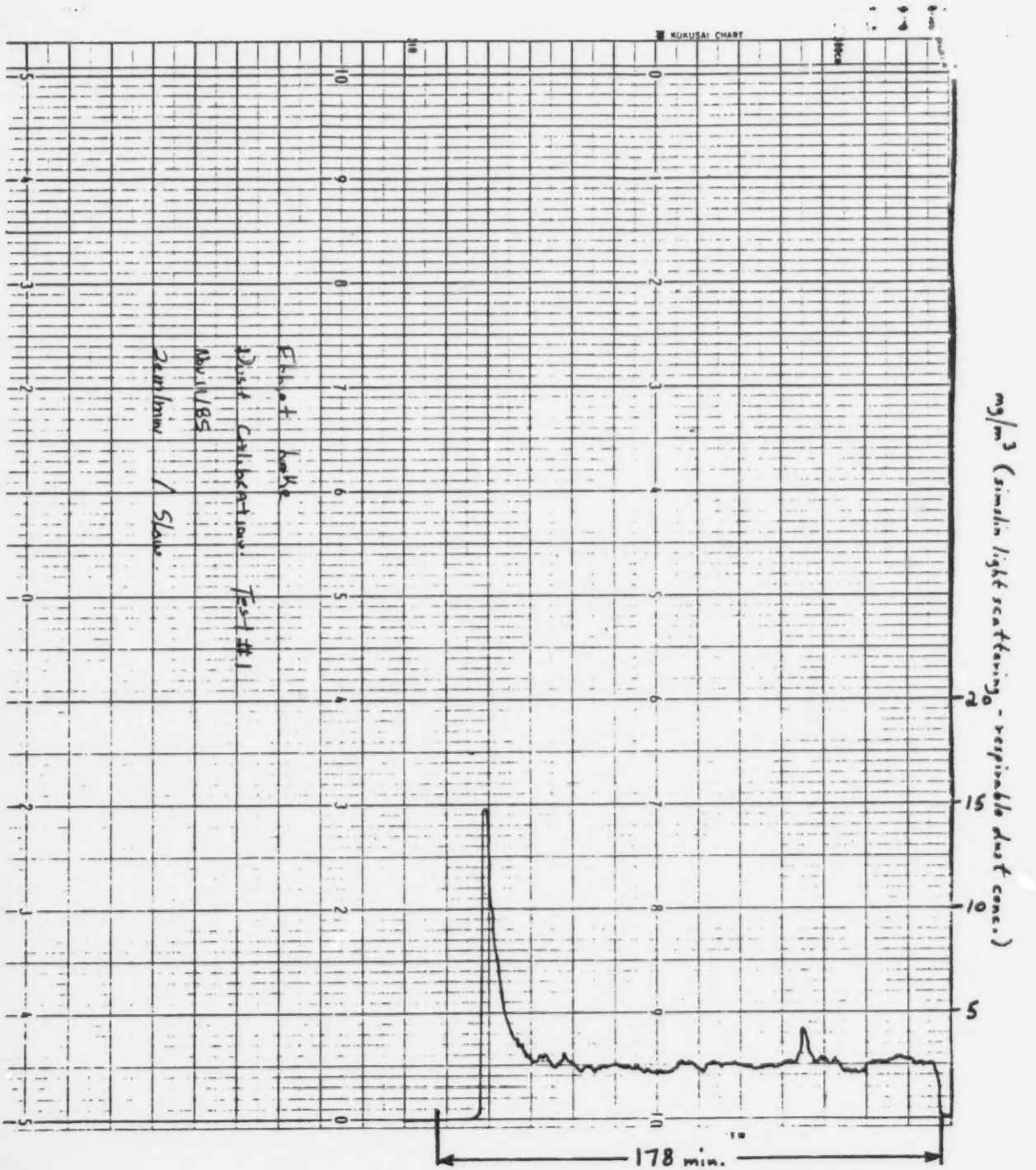
We acknowledge the invaluable help and support provided by Mr. G. Knight and Dr. S. Hardcastle (MRL, Elliot Lake) and for the use of their dust chamber and laboratory facilities.

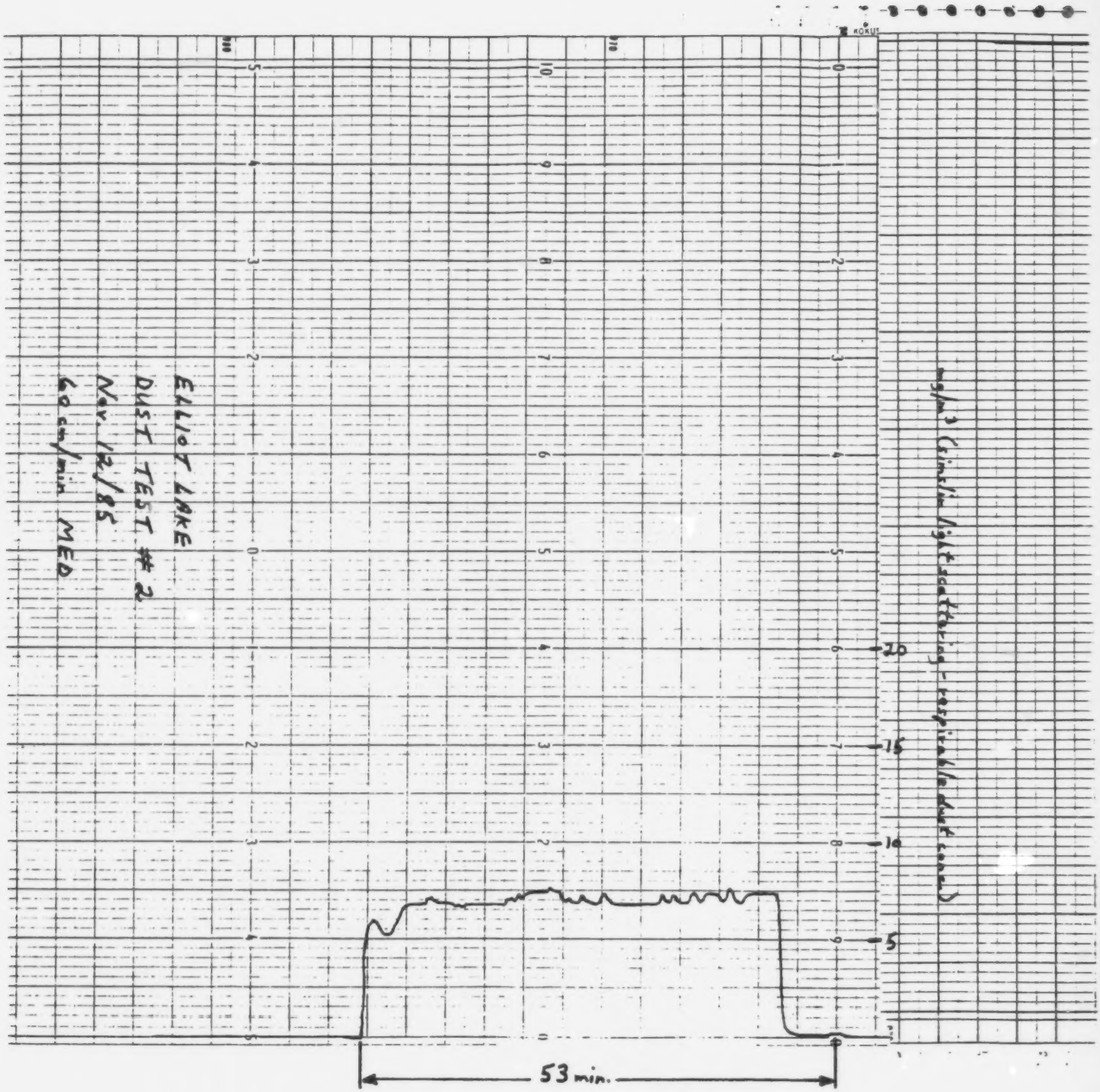
REFERENCES

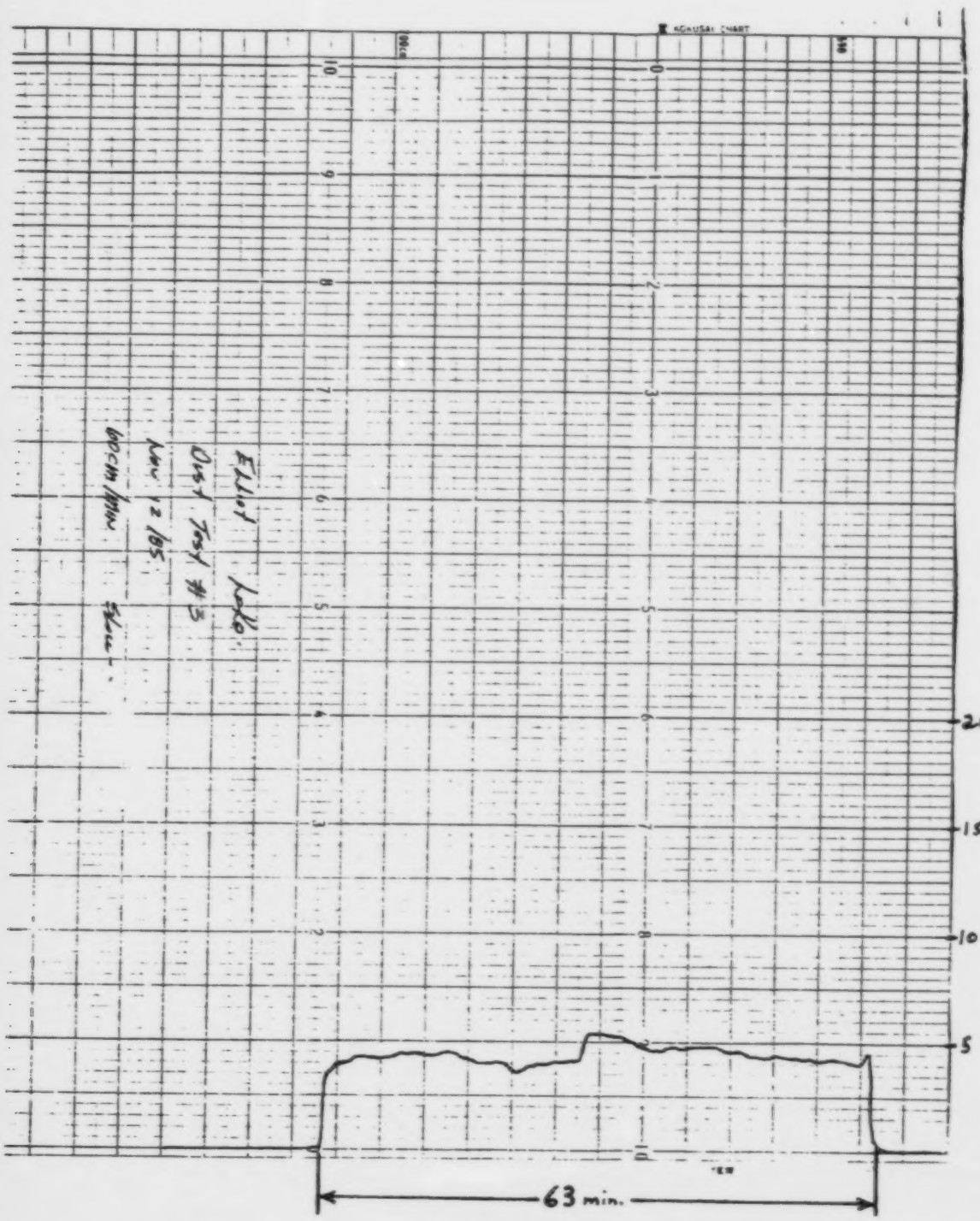
1. Hwang, J.C.Y. and Stewart, D.B. "CBCRL's respirable dust research program December 1984"; CANMET Division Report ERP/CRL 84-58(TR); 1984.
2. Hwang, C.Y., Kennedy, D.J. and Bonnell, G.W. "Respirable dust measurements made at Lingan Colliery during the period December 1984 - March 1985: Part I"; CANMET Division Report ERP/CRL 85-68(CF); 1985.
3. Hwang, C.Y., Bonnell, G.W., Corbett, G.R., MacNeil, C.H., Young, D.A., O'Leary, L.S. and O'Brien, D.J. "Respirable dust measurements made at Prince Colliery during the period December 1985 - June 1986"; CANMET Division Report ERP/CRL 86-131(CF); 1986.
4. Hwang, C.Y. "Measurements of respirable dust concentrations by using various samplers in underground coal mines"; CANMET Division Report ERP/CRL 86-105(J,OP); 1986.
5. Knight, G. "Mine dust sampling system - CAMPEDS"; CANMET Report 78-7; CANMET; Energy, Mines and Resources Canada; 1978.
6. Knight, G. and Moore, E. "Comparison of respirable dust samplers for use in hard rock mines"; CANMET Division Report MRP/MRL 84-78(OP)(J); 1984.
7. Knight, G. and Moore, E. "Comparison of dust samplers: statistical analysis techniques"; CANMET Division Report MRP/MRL 84-79(OP)(J); 1984.
8. Knight, G. "Gravimetric sampling: pratical problems"; revision of Division Report MRP/MRL 84-92(OP,J); 1985.
9. Young, D. "Pump calibration procedures for dust sampling instruments used at CBCRL"; in preparation.
10. Corbett, G. "A study of the filters used in the dust research program at Cape Breton Coal Research Laboratory"; CANMET Division Report CRL 87-24(TR); March 1987.
11. O'Brien, D.J. "Portal-to-portal dust sampling procedures used at CBCRL"; CANMET Division Report CRL 87-28(TR); March 1987.

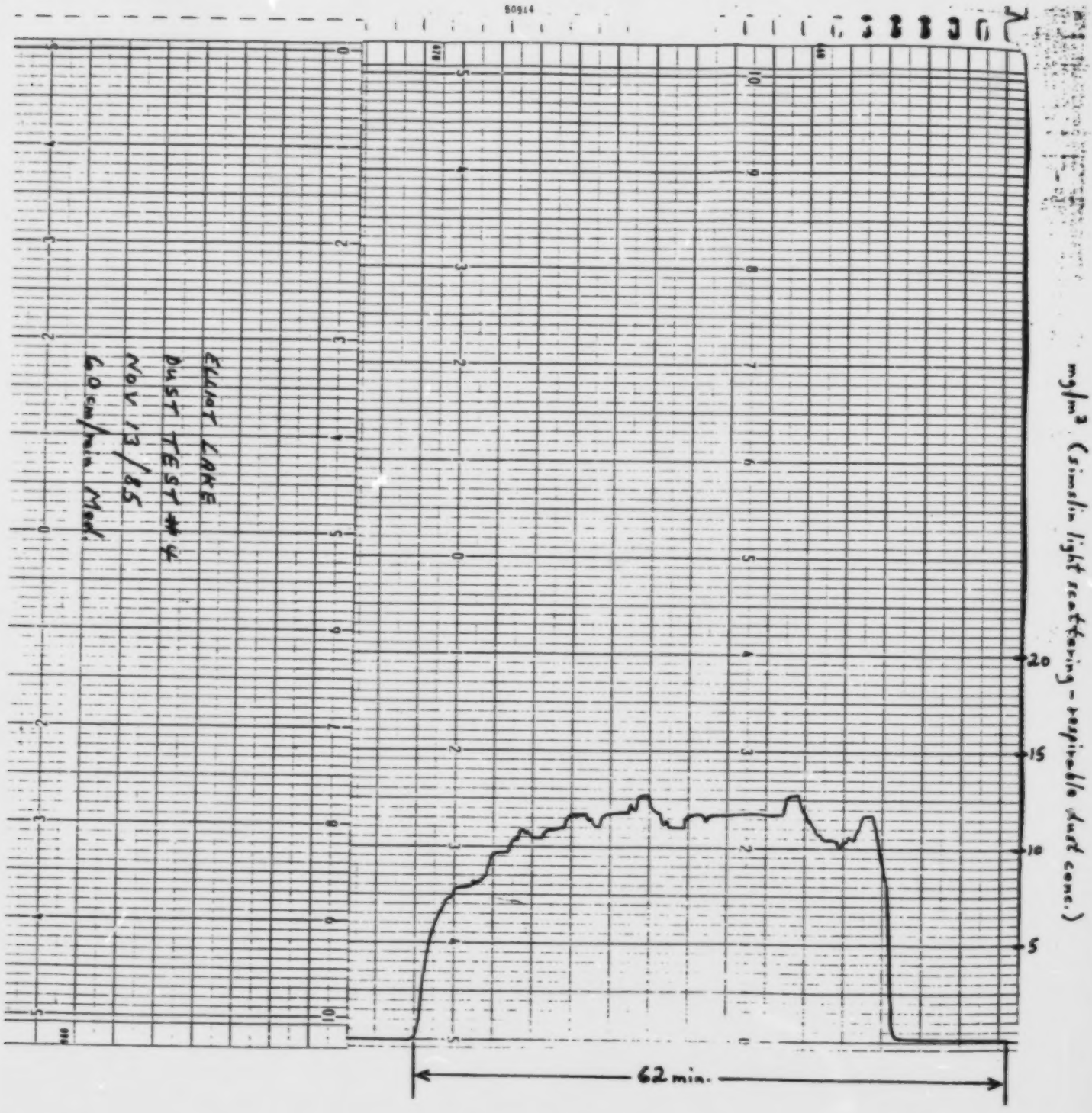
APPENDIX A

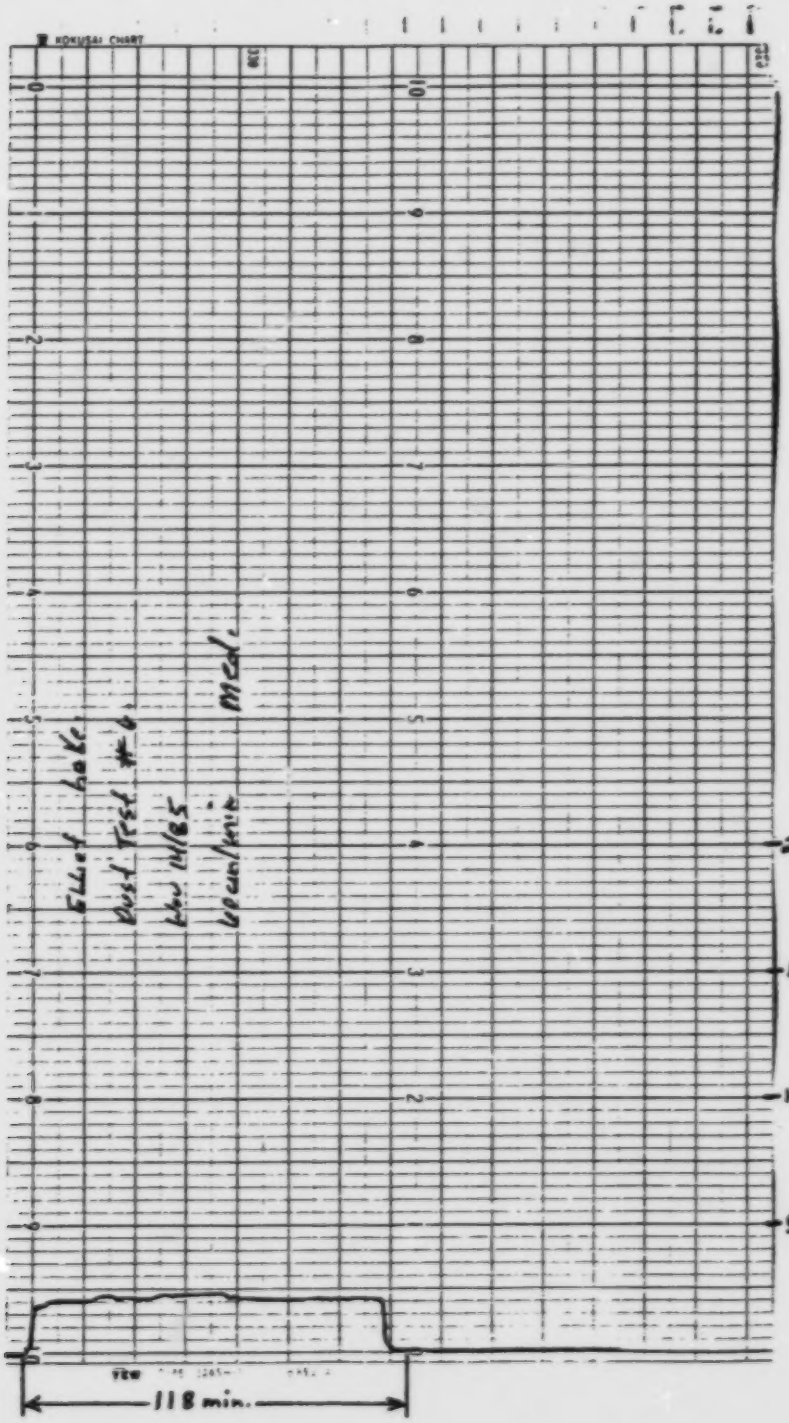
SIMSLIN II Light-Scattering Charts


KOKUSAI CHART
Elbert Lake
Dust Calibration Test #1
April 1985
2cm/min / Slow
mg/m³ (simulin light scattering - respirable dust conc.)
178 min.


ELLIOT LAKE
DUST TEST # 2
Nov. 12/85
60 cm/min MED
mg/m³ (Gravimetric light scattering - respirable dust trend)
53 min.


Elliot Lake
Dust Test #3
Nov 12 1985
Bodem Mine
63 min.
20
15
10
5
mg/m3 (simulin light scattering - respirable dust conc.)

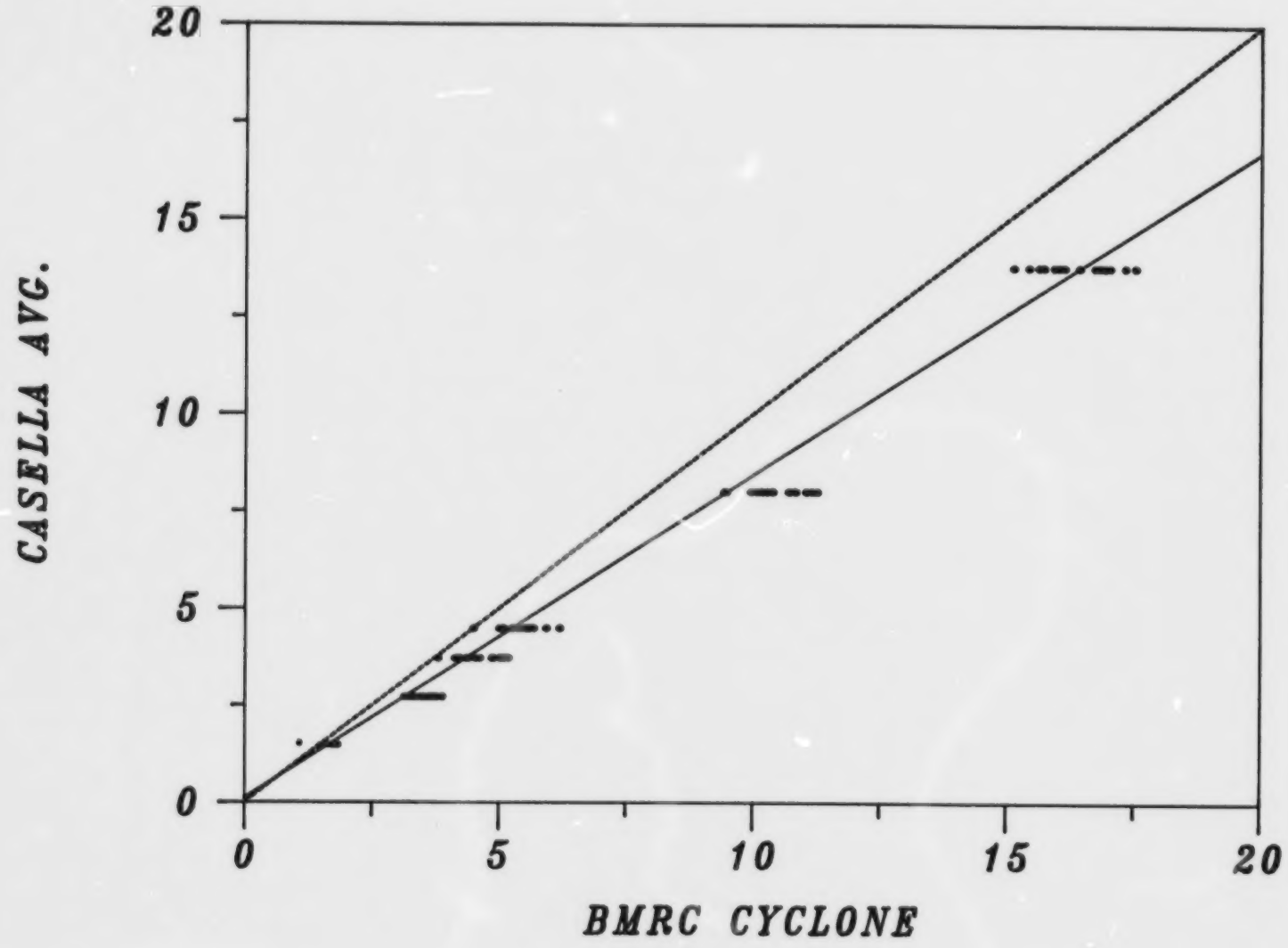

ELLIOT LAKE
DUST TEST #4
NOV 13/85
60 cm/min Med.
62 min.
mg/m³ (simslin light scattering - respirable dust conc.)
20
15
10
5

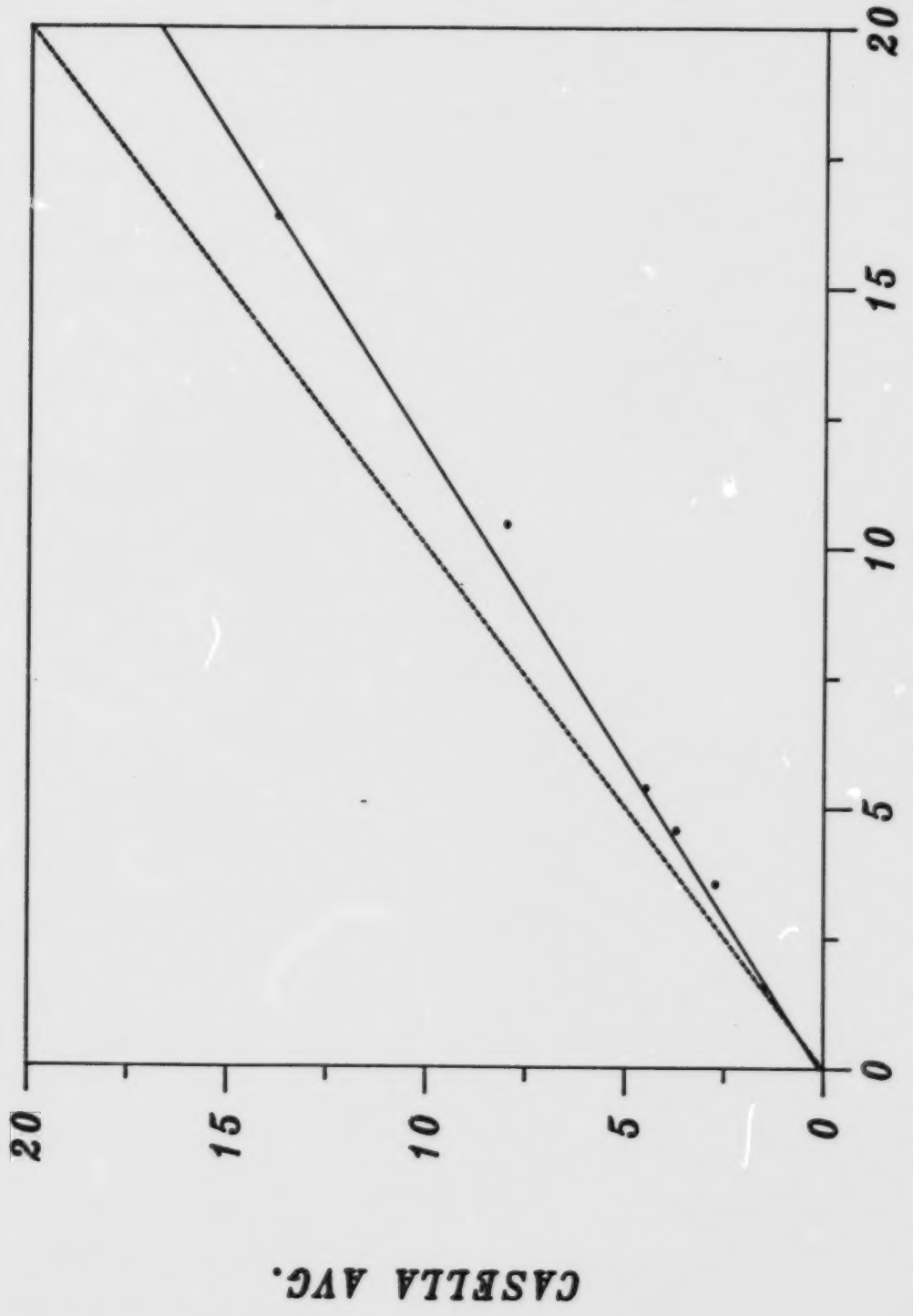


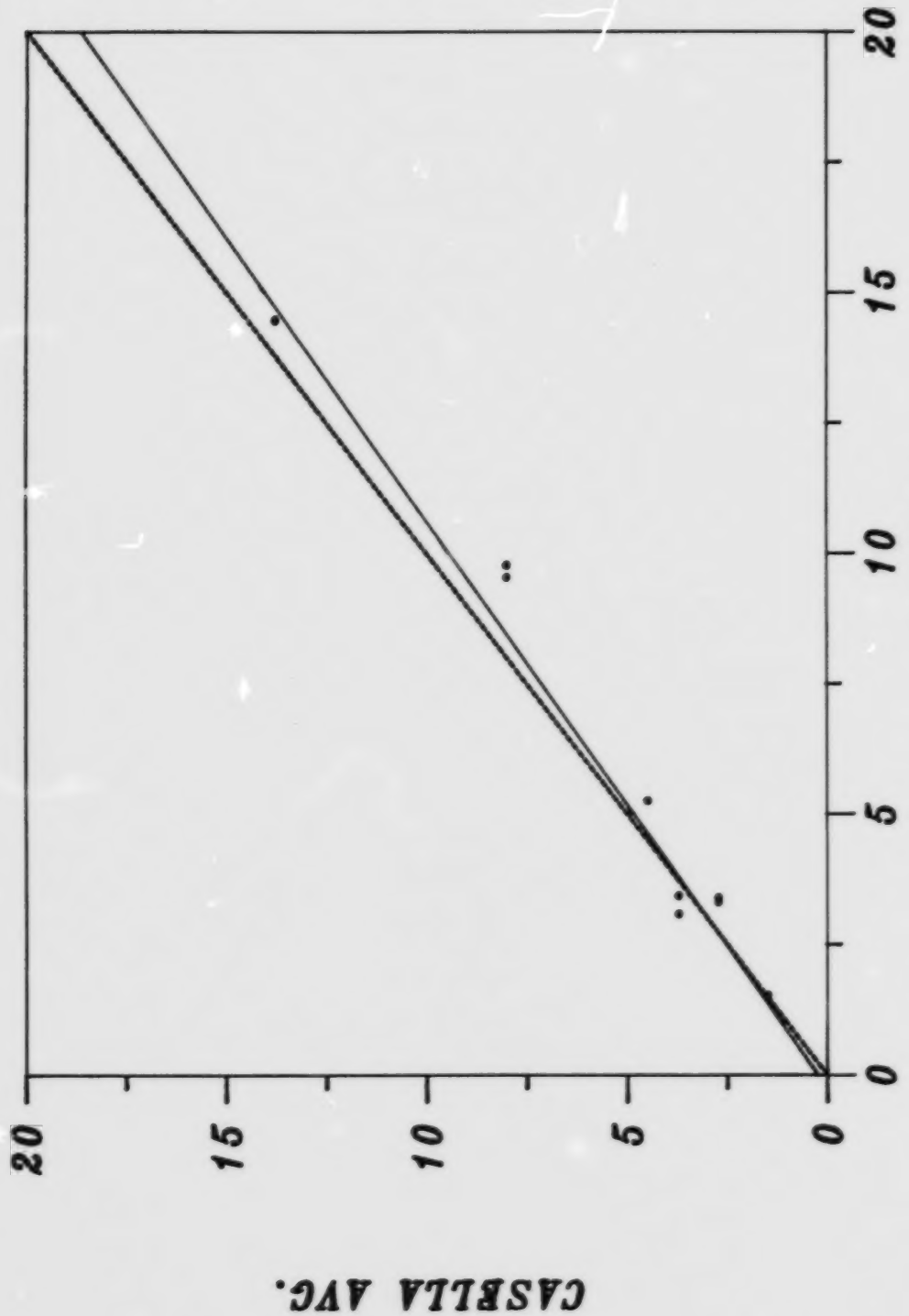
mg/m³ (simulin light scattering - respirable dust conc.)

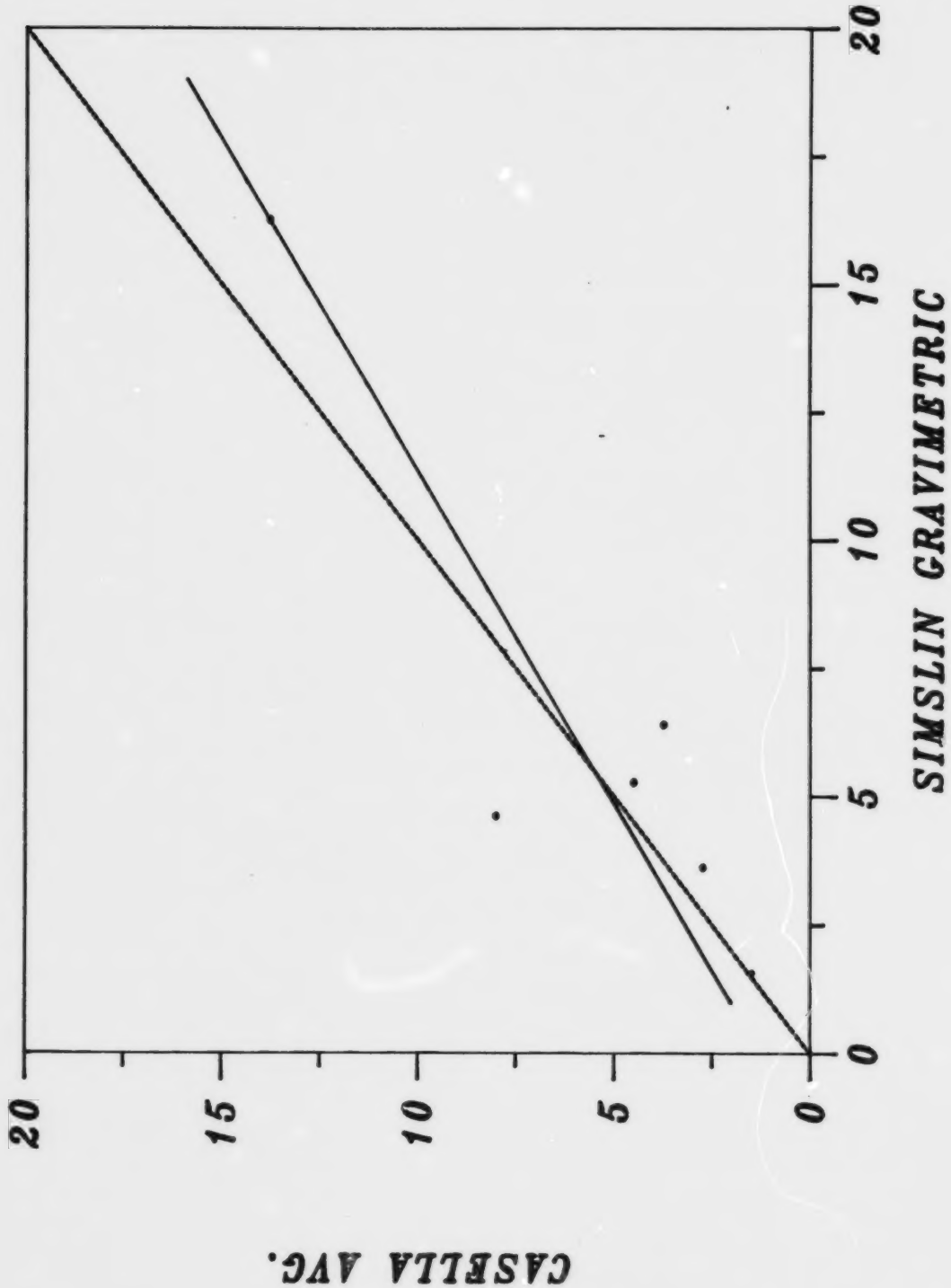
APPENDIX B

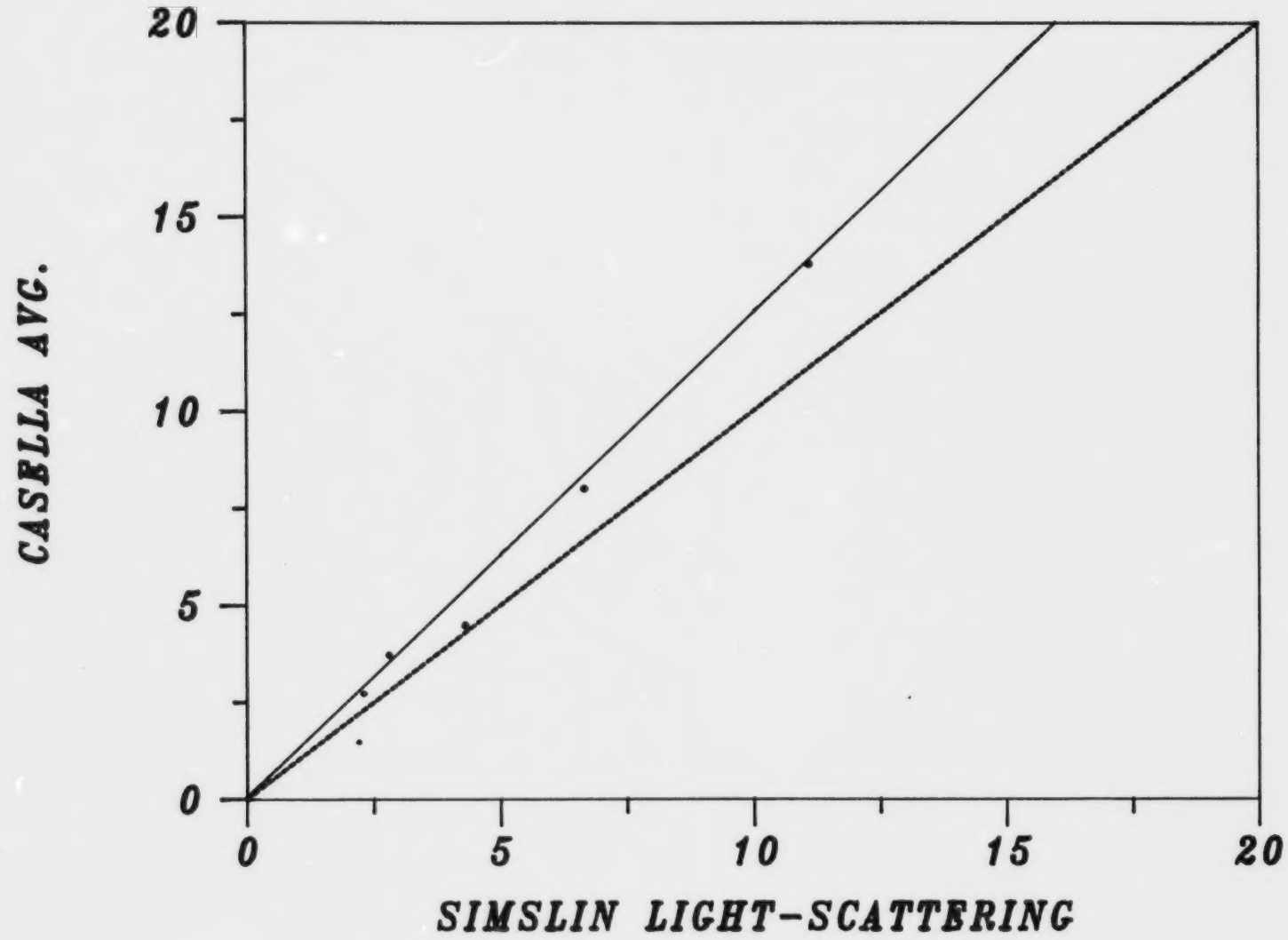
Sampling Systems vs Casella Average

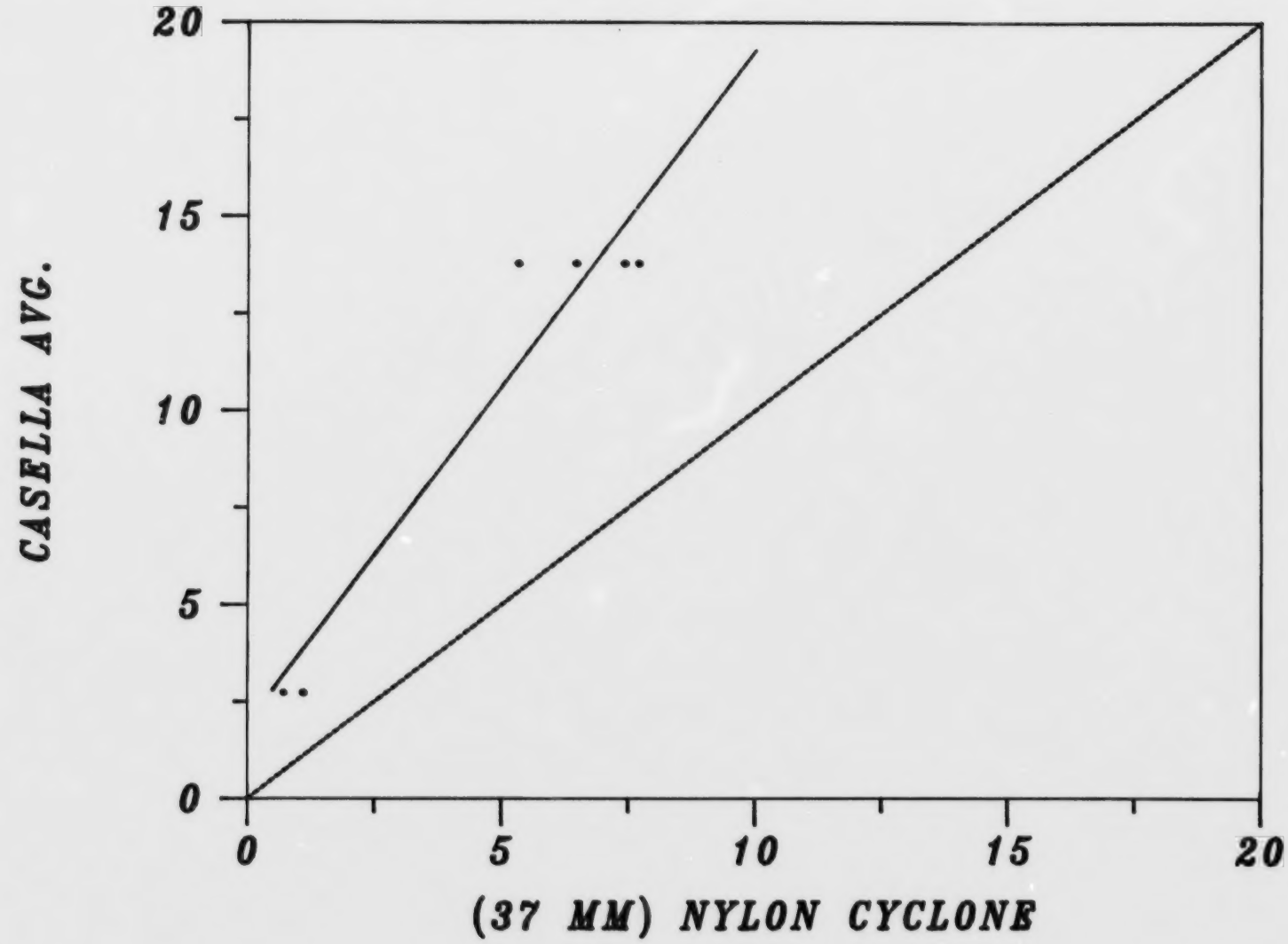

20
15
10
5
0
0
5
10
15
20
CASELLA AVG.
BMRC CYCLONE

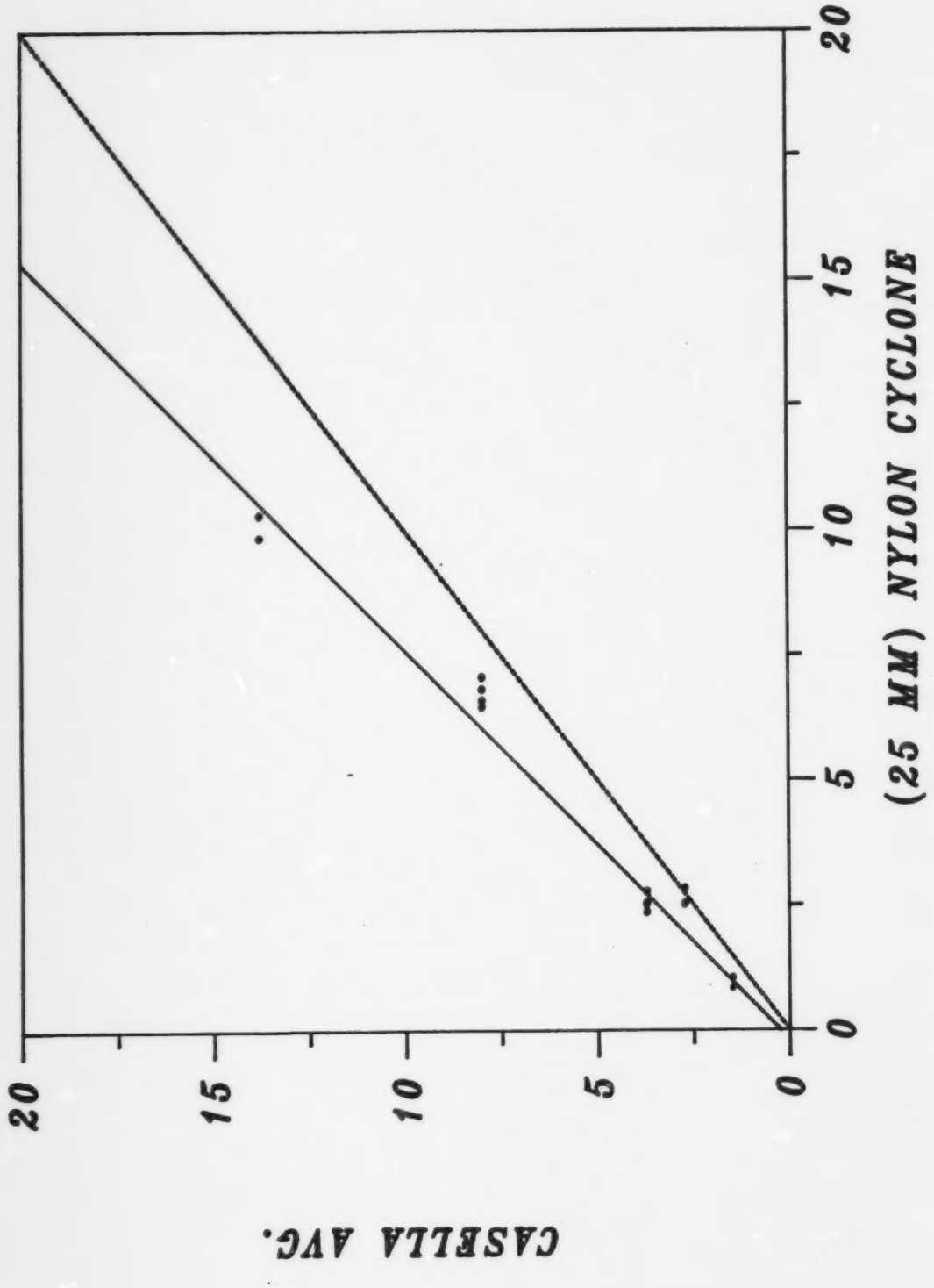

0
5
10
15
20
BMRC CYCLONE AVG.
0
5
10
15
20
CASELLA AVG.

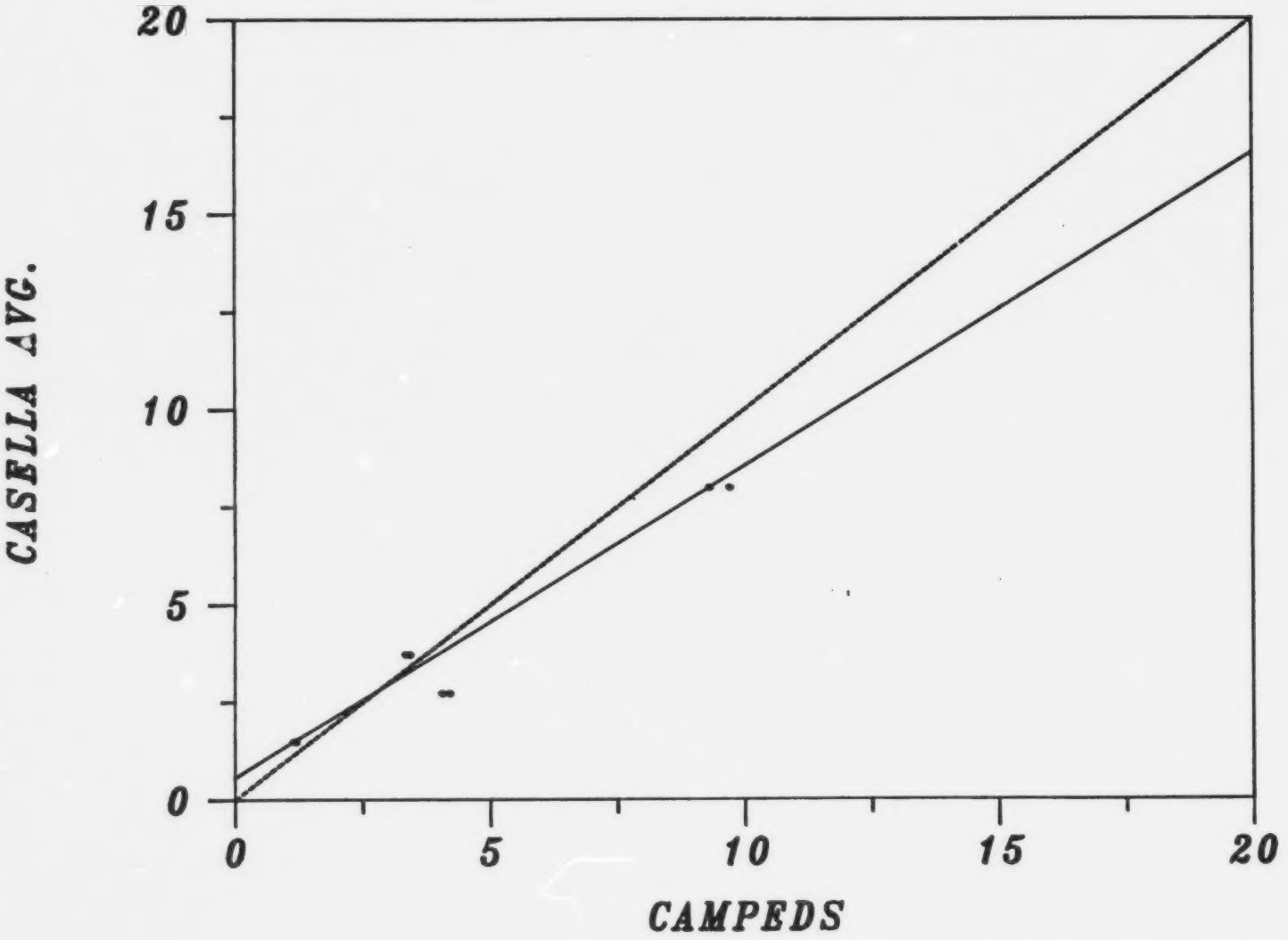

CASELLA AVG.
HEXHLET
0
5
10
15
20


0
5
10
15
20
SIMSLIN GRAVIMETRIC
0
5
10
15
20
CASELLA AVG.


20
15
10
5
0
CASELLA AVG.
0
5
10
15
20
SIMSLIN LIGHT-SCATTERING

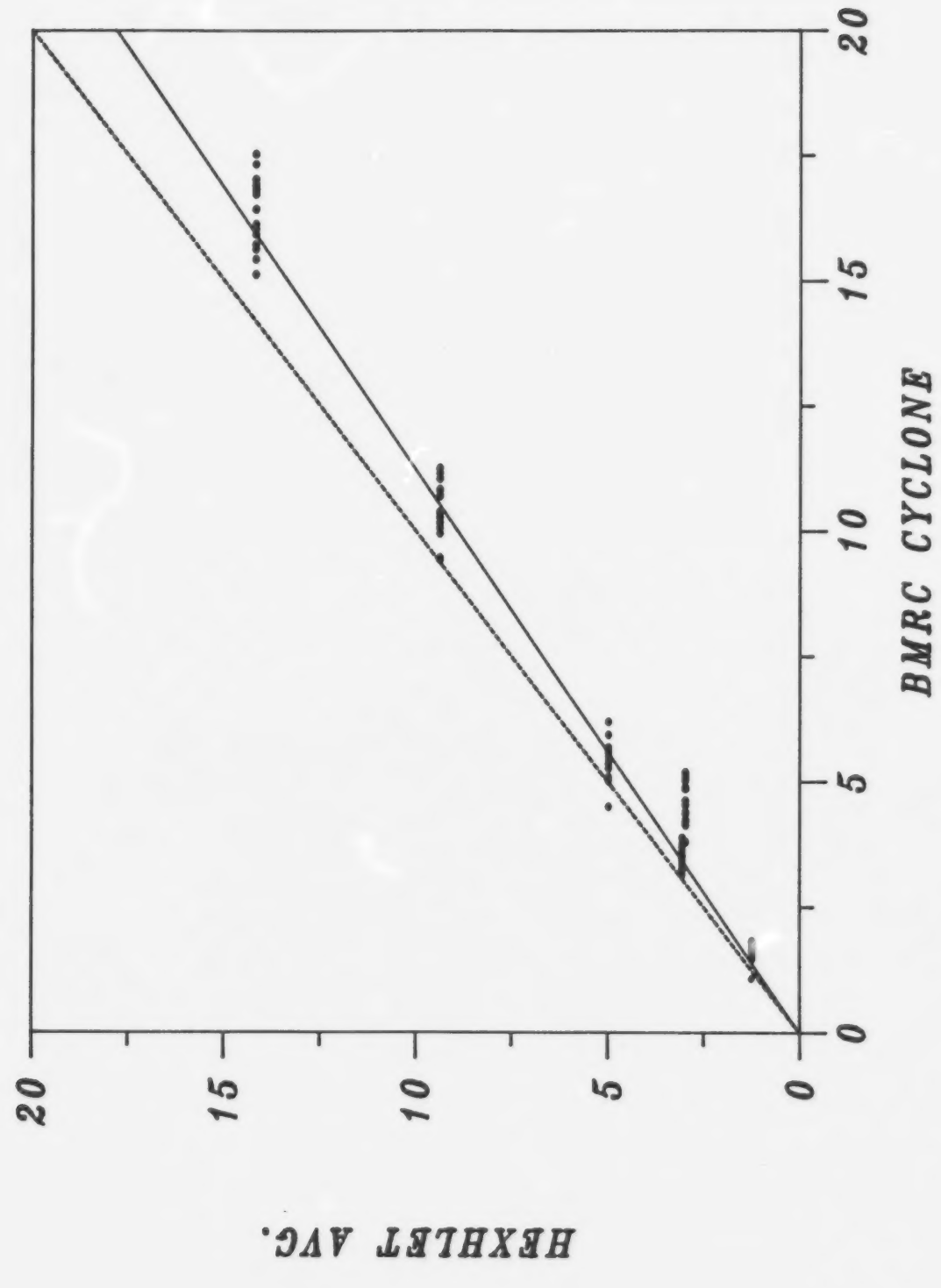

CASELLA AVG.
20
15
10
5
0
0
5
10
15
20
(37 MM) NYLON CYCLONE

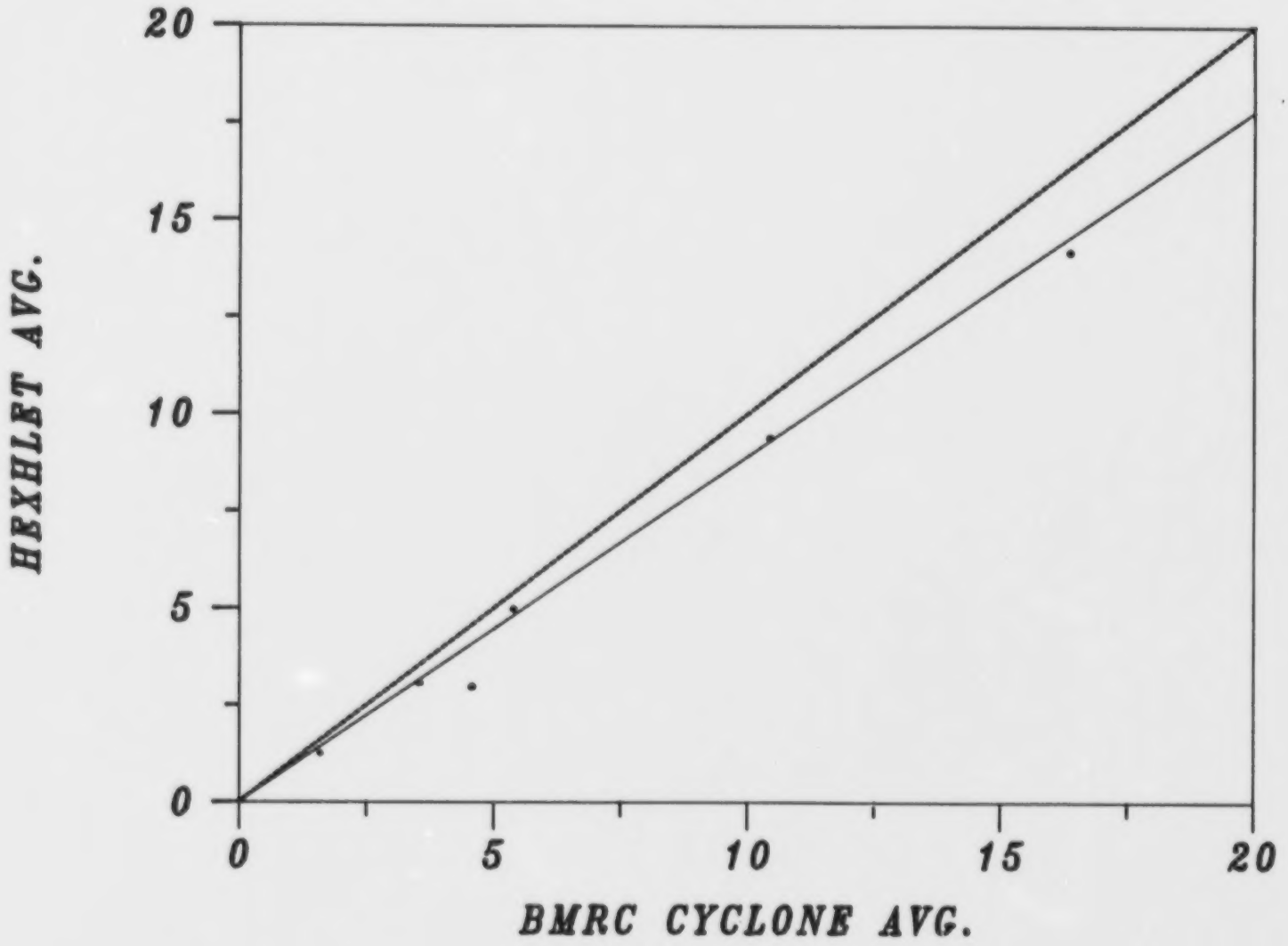

CASELLA AVG.
0
5
10
15
20
0
5
10
15
20
(25 MM) NYLON CYCLONE

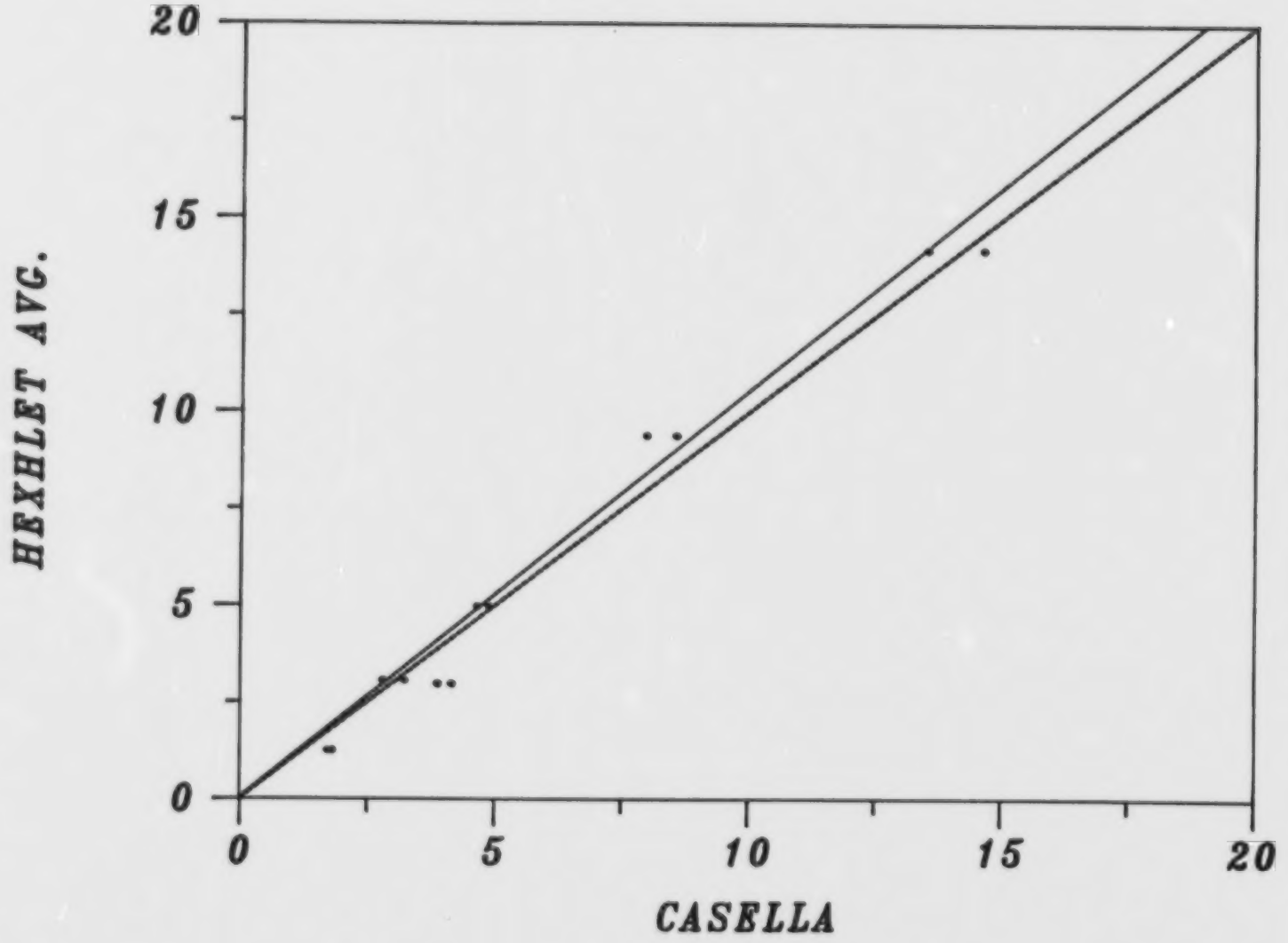

20
15
10
5
0
CASELLA AVG.
0
5
10
15
20
CAMPEDS

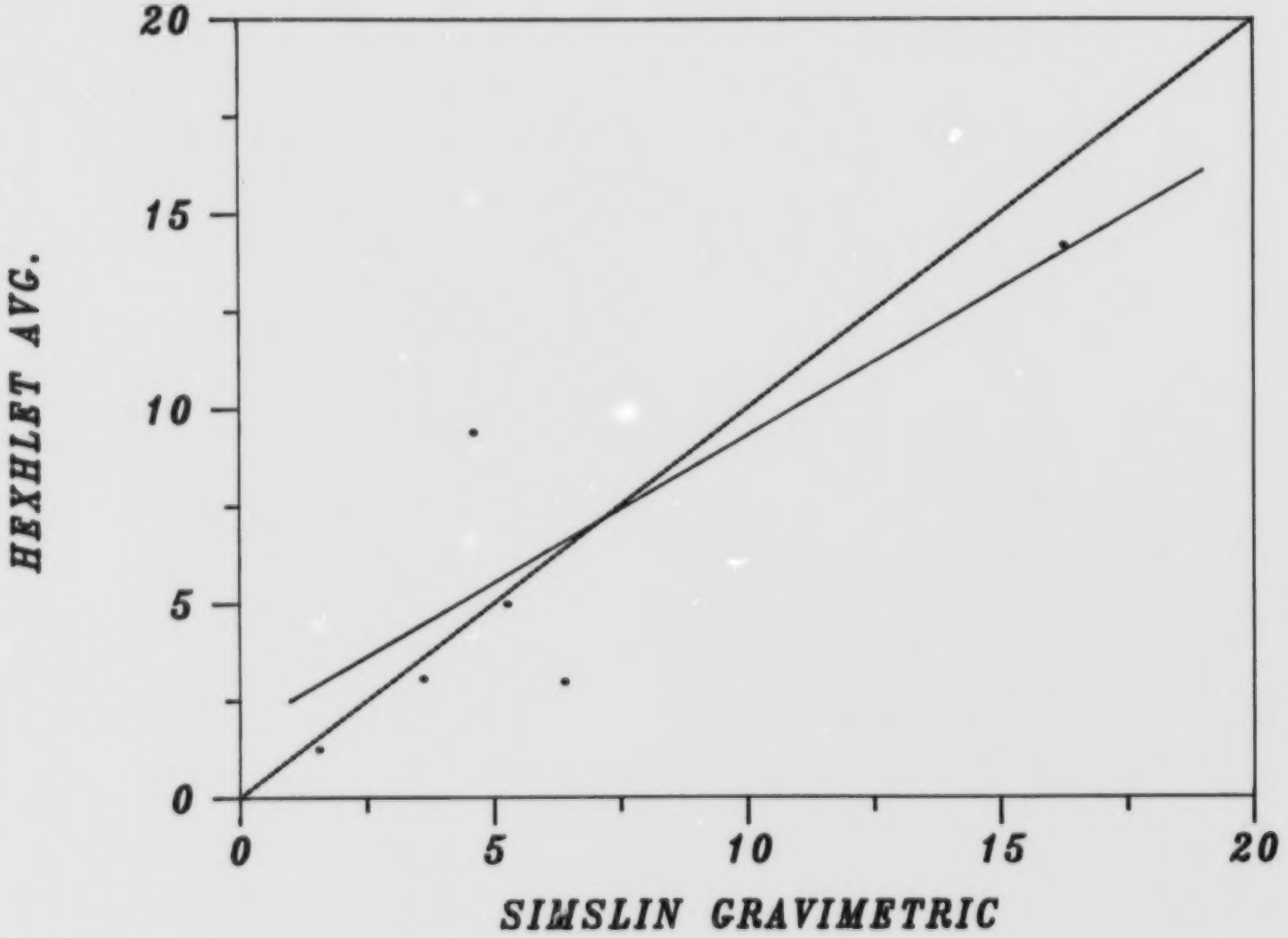
APPENDIX C

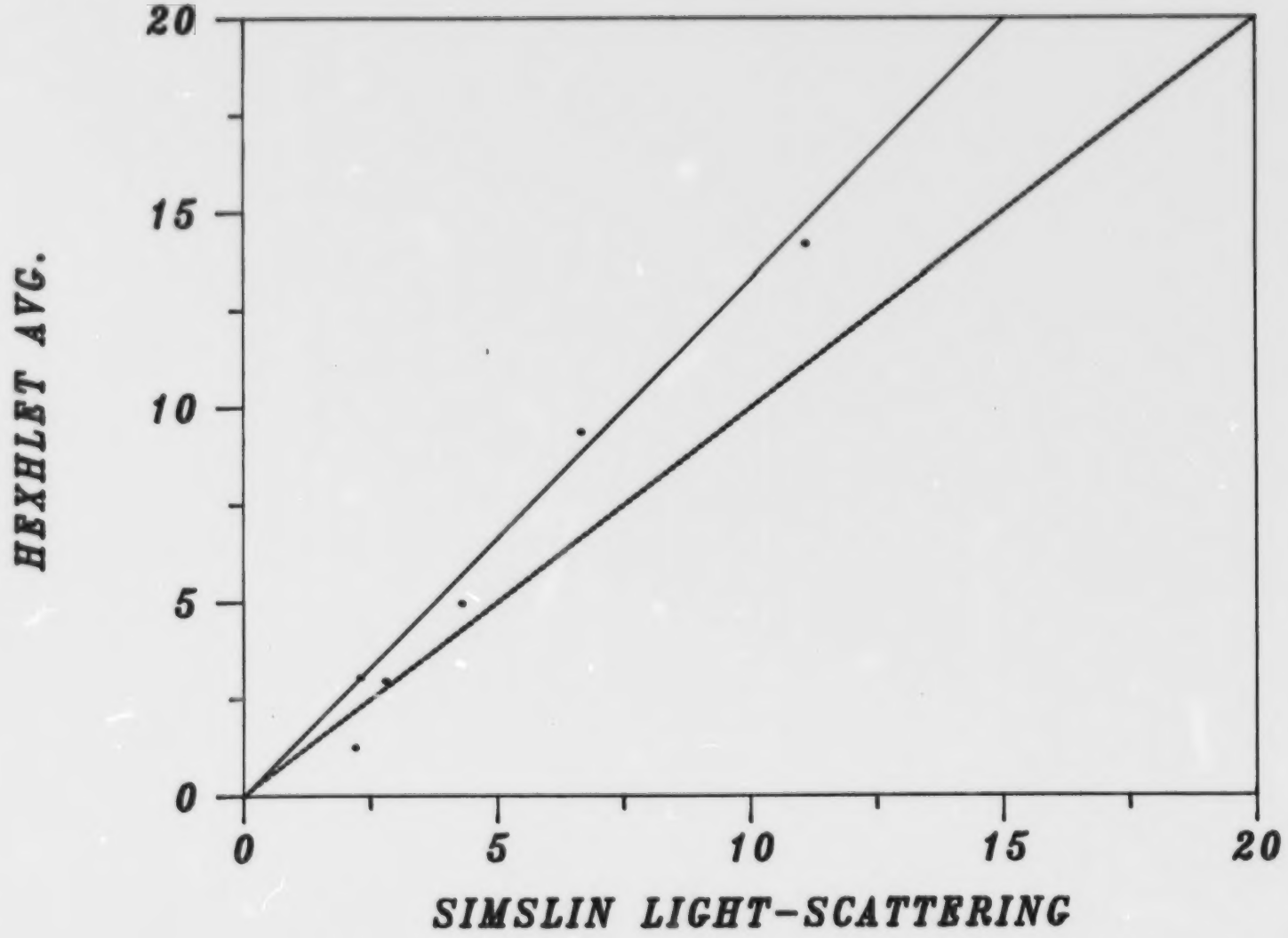
Sampling Systems vs Hexhlet Average

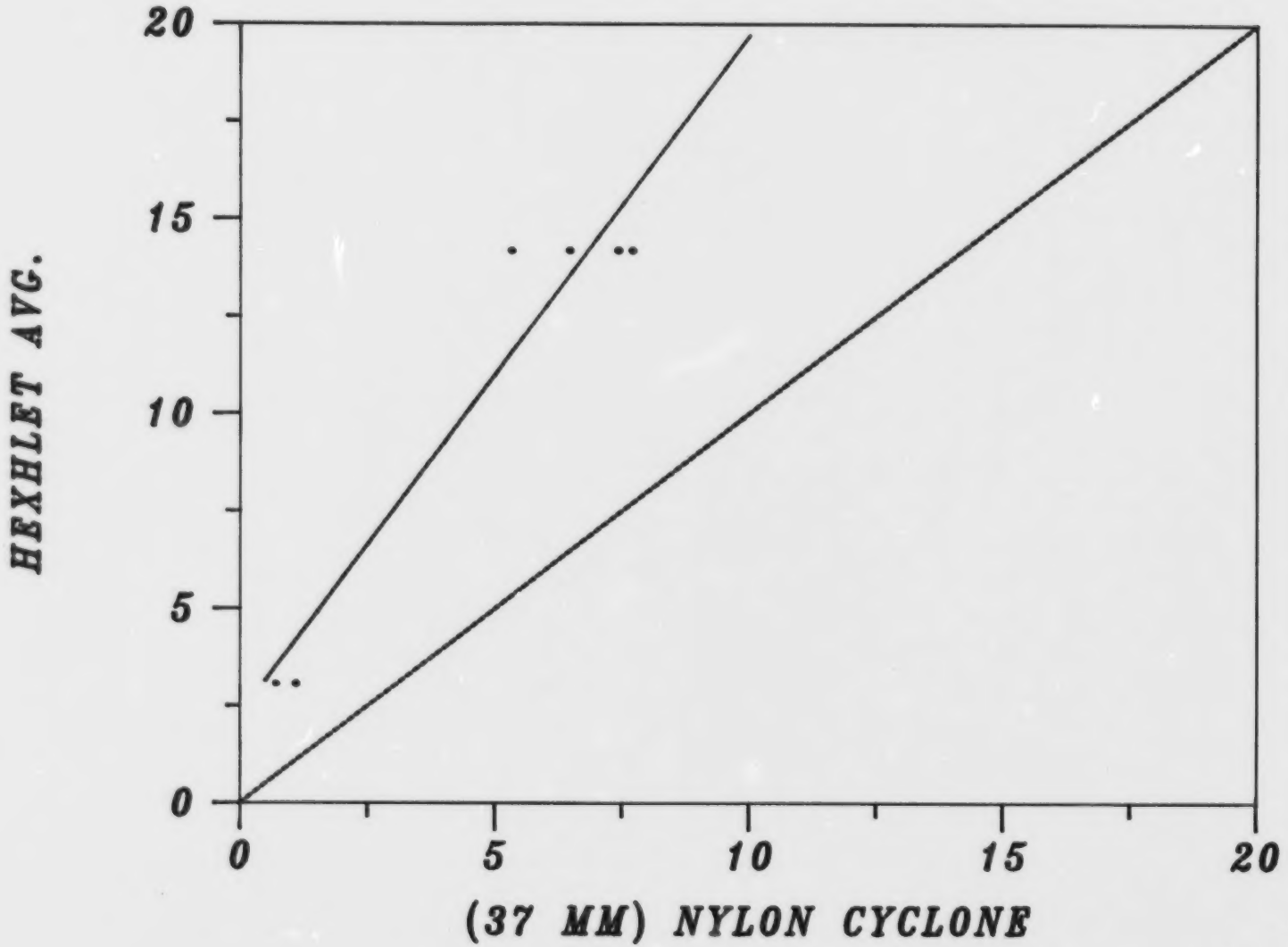

HEXHLET AVG.
0
5
10
15
20
0
5
10
15
20
BMRC CYCLONE

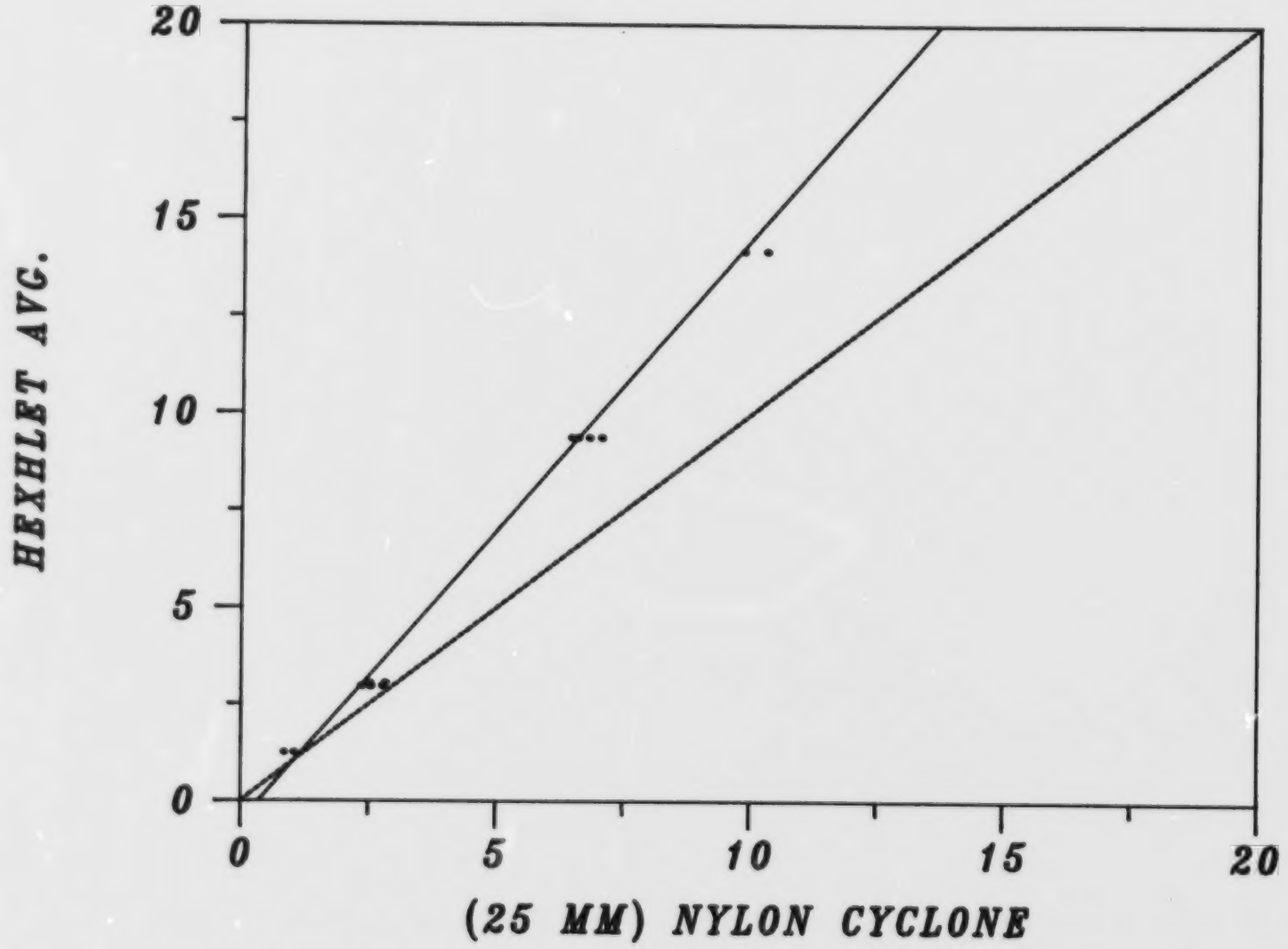

20
15
10
5
0
HEXHLET AVG.
0
5
10
15
20
BMRC CYCLONE AVG.

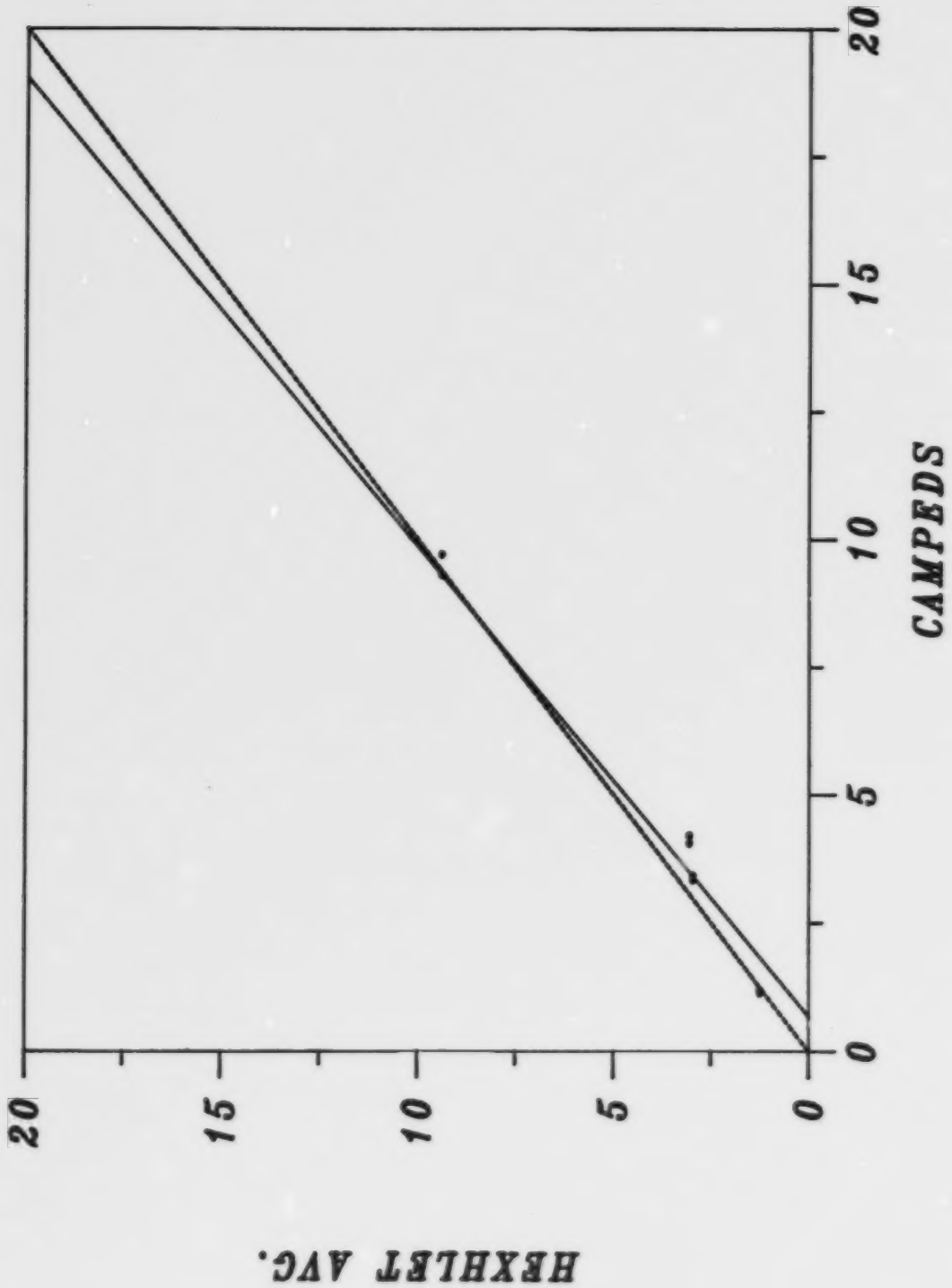

HEXHLET AVG.
20
15
10
5
0
0
5
10
15
20
CASELLA


20
15
10
5
0
HEXHLET AVG.
0
5
10
15
20
SIMSLIN GRAVIMETRIC


20
15
10
5
0
0
5
10
15
20
HEXHLET AVG.
SIMSLIN LIGHT-SCATTERING

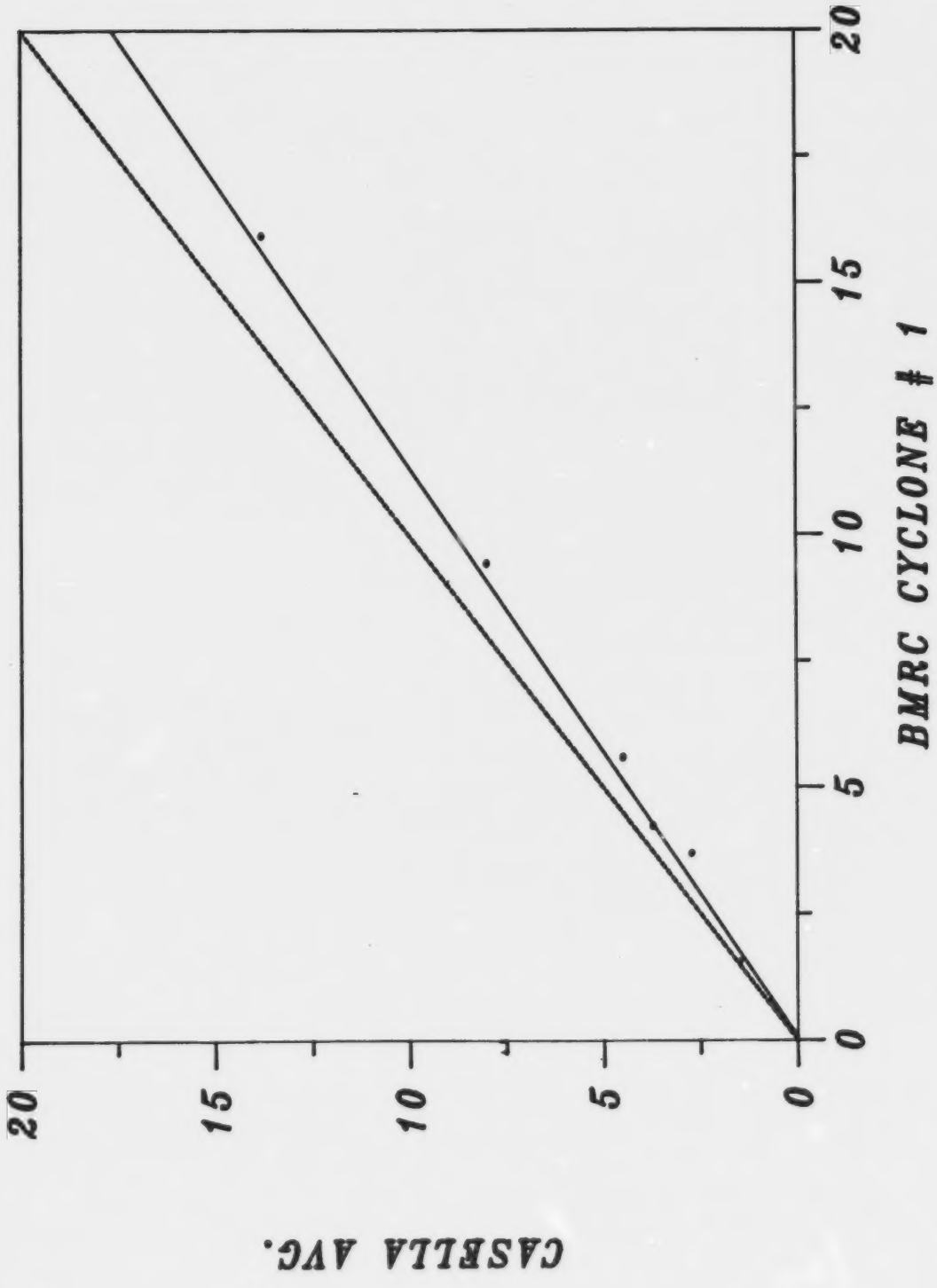

HEXHLET AVG.
20
15
10
5
0
0
5
10
15
20
(37 MM) NYLON CYCLONE

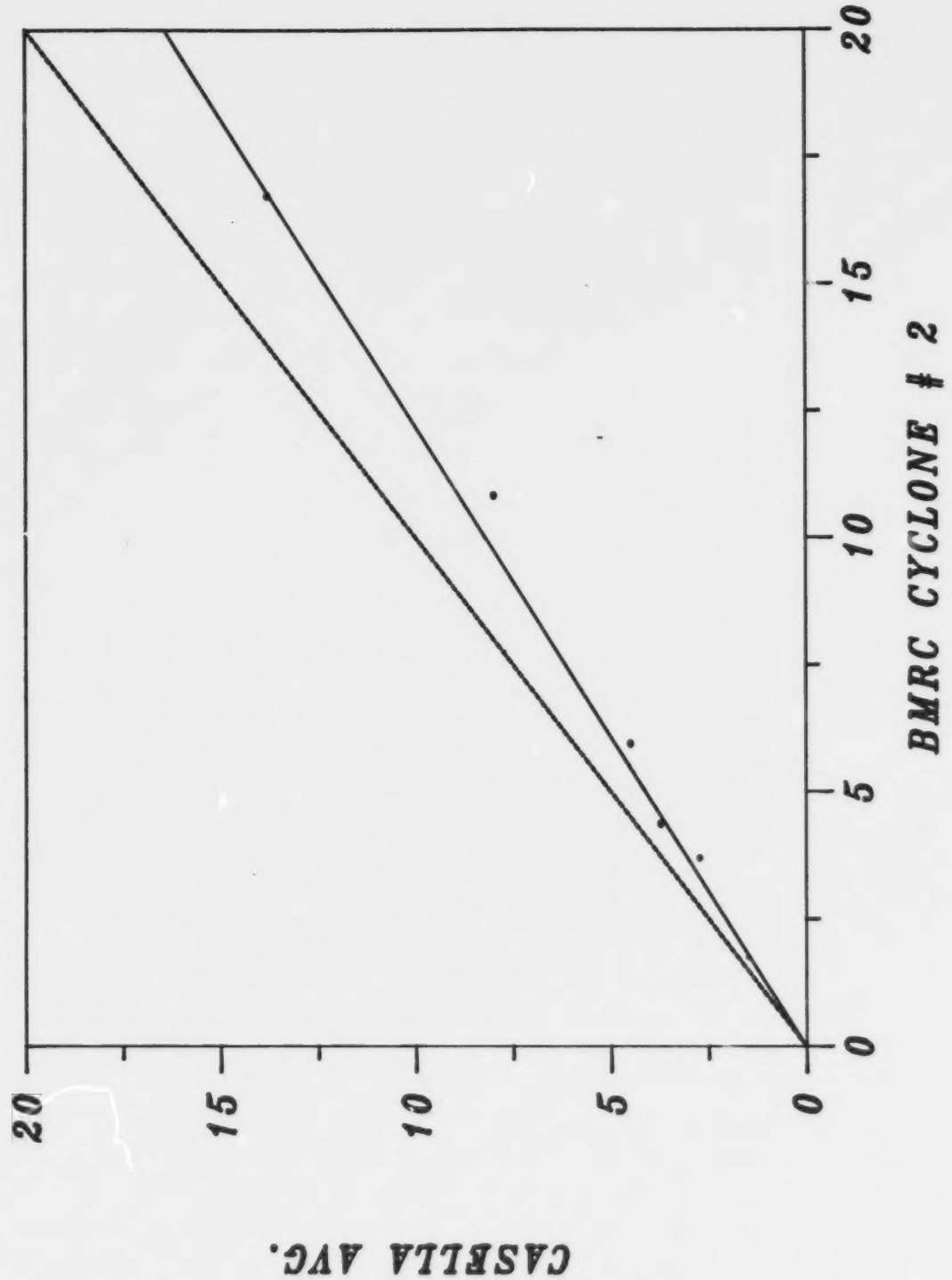

20
15
10
5
0
HEXHLET AVG.
0
5
10
15
20
(25 MM) NYLON CYCLONE

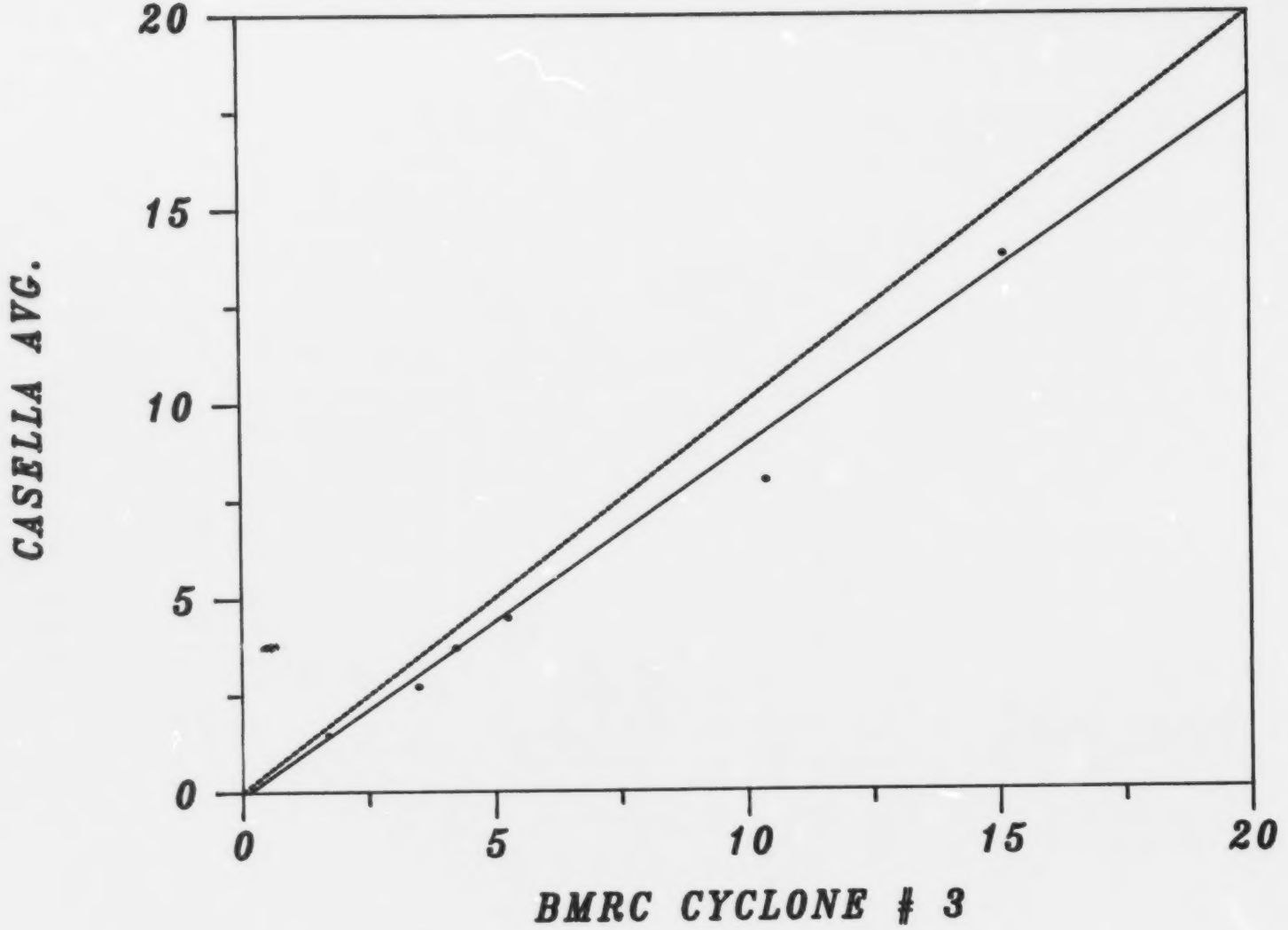

HEXHLET AVG.
0
5
10
15
20
0
5
10
15
20
CAMPEDS

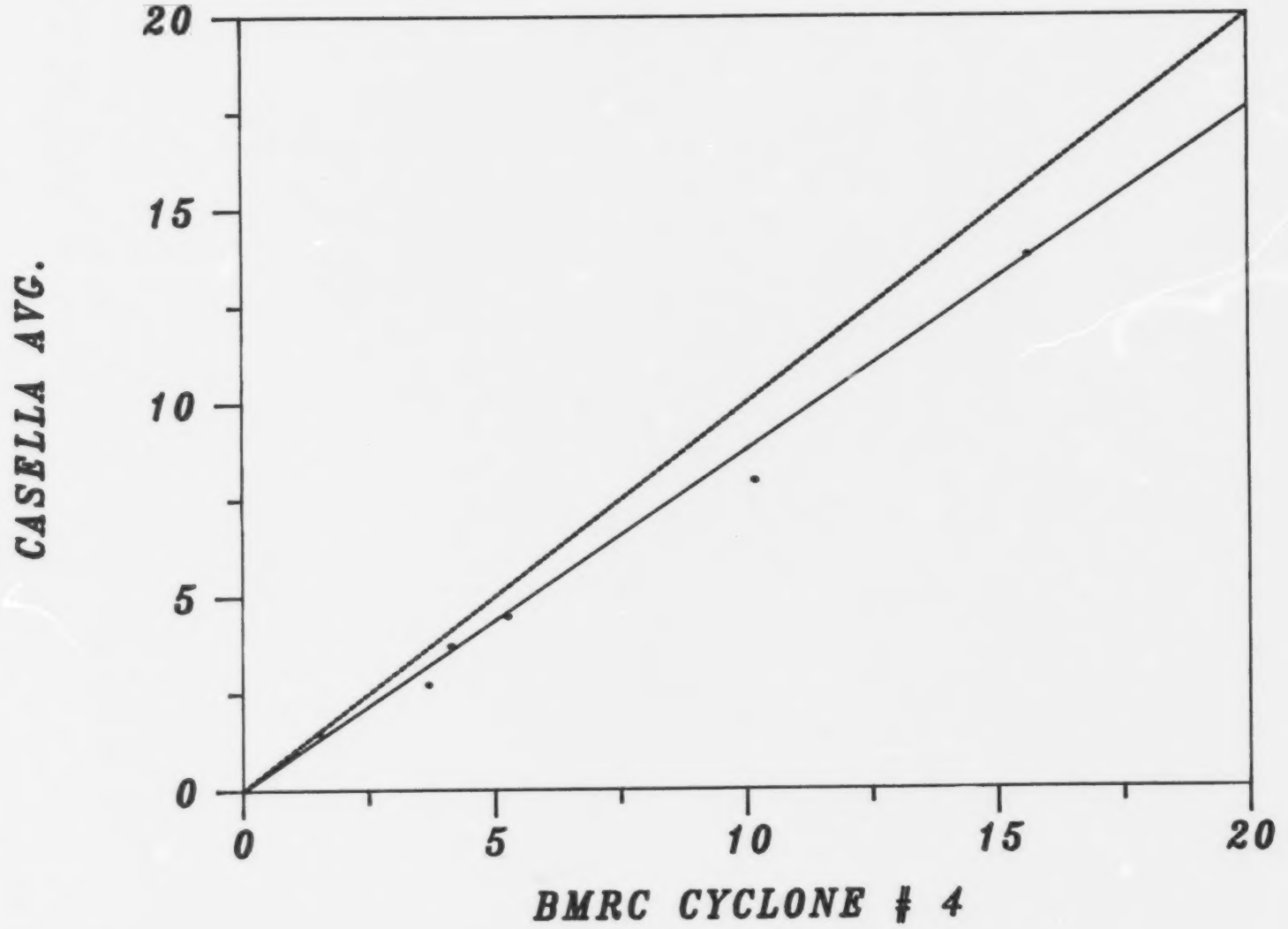
APPENDIX D

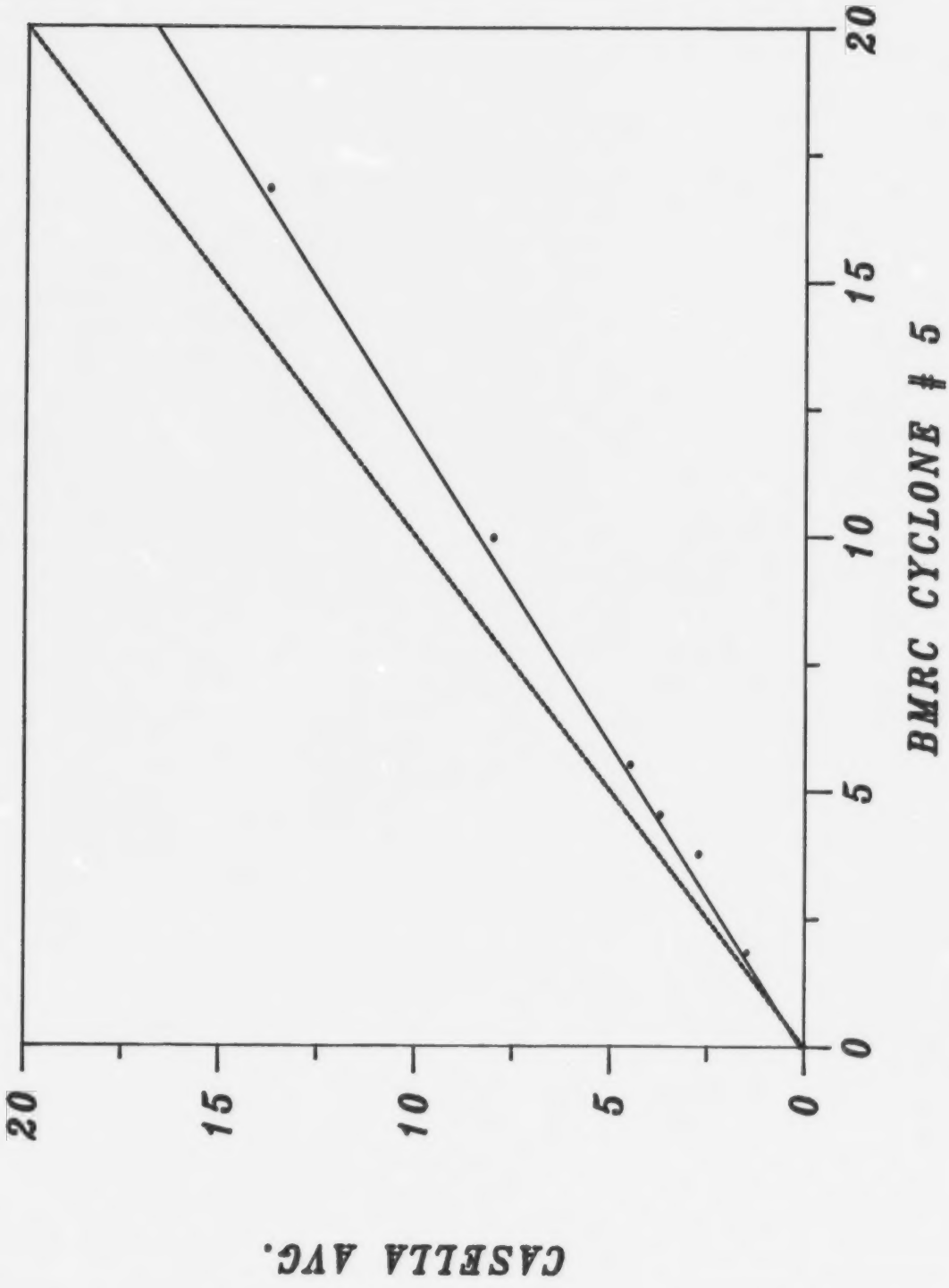
BMRC Cyclones vs Casella Average

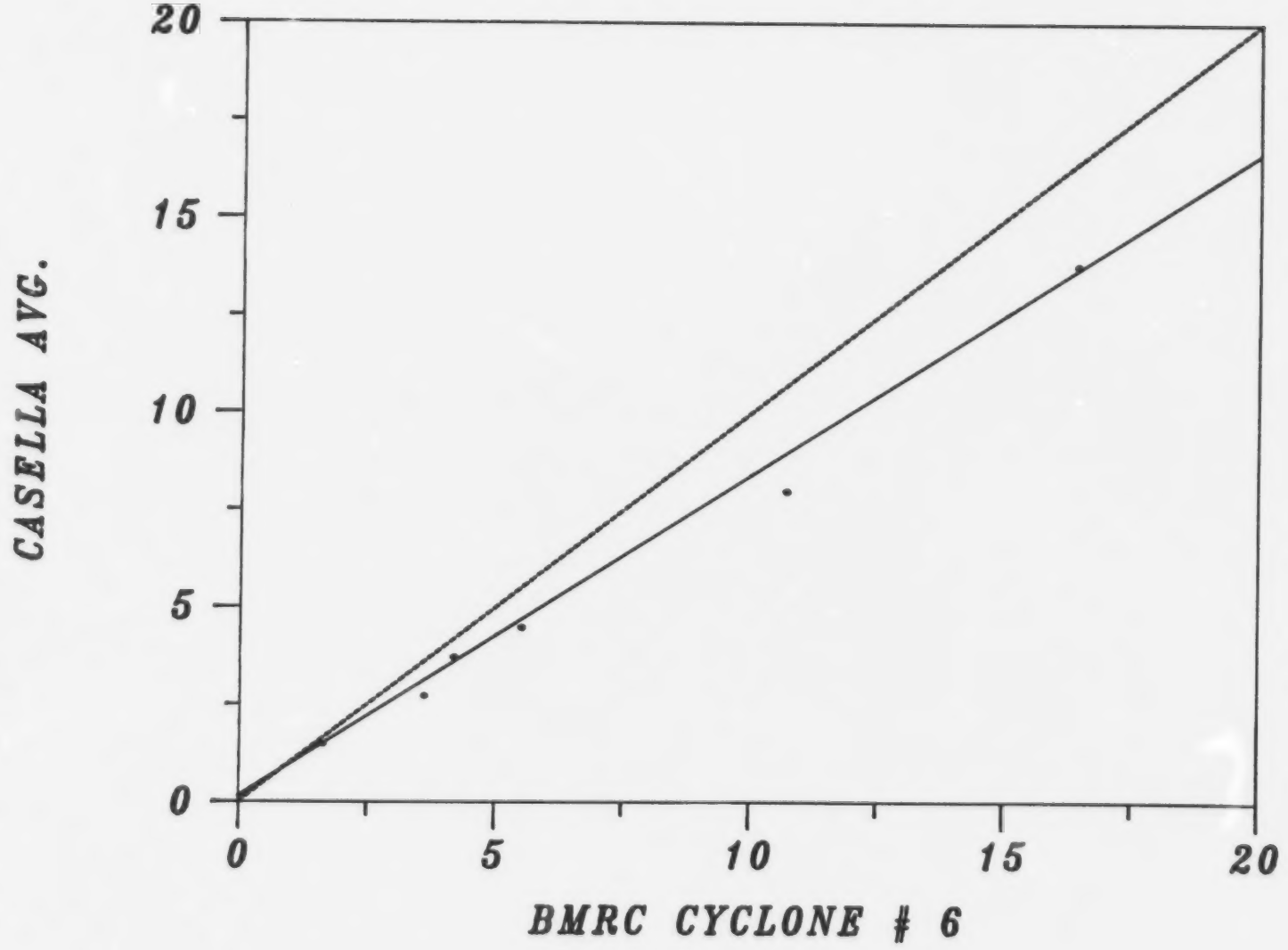

BMRC CYCLONE # 1
CASELLA AVG.
0
5
10
15
20

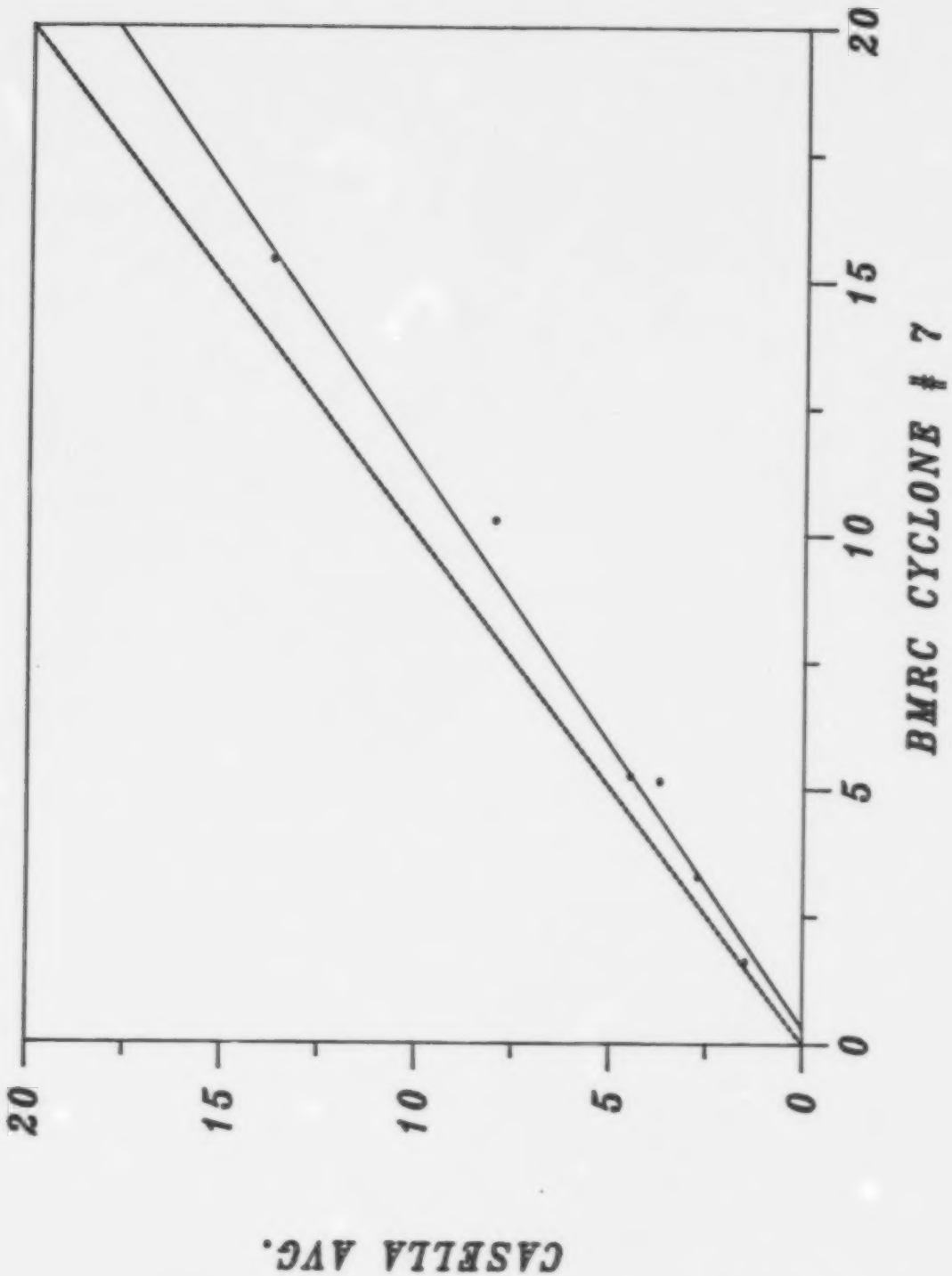

BMRC CYCLONE # 2
CASELLA AVG.
0
5
10
15
20

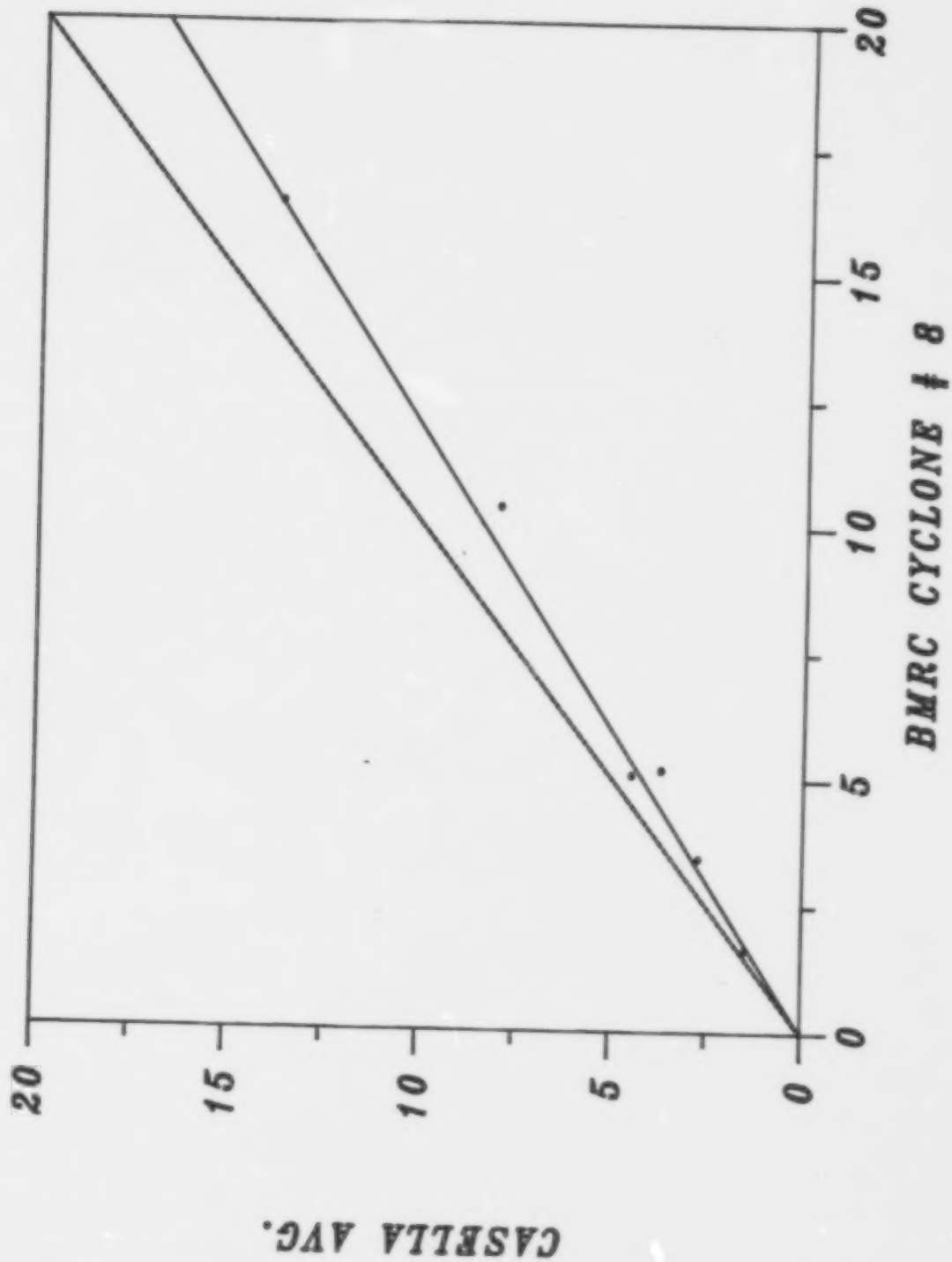

20
15
10
5
0
0
5
10
15
20
CASELLA AVG.
BMRC CYCLONE # 3

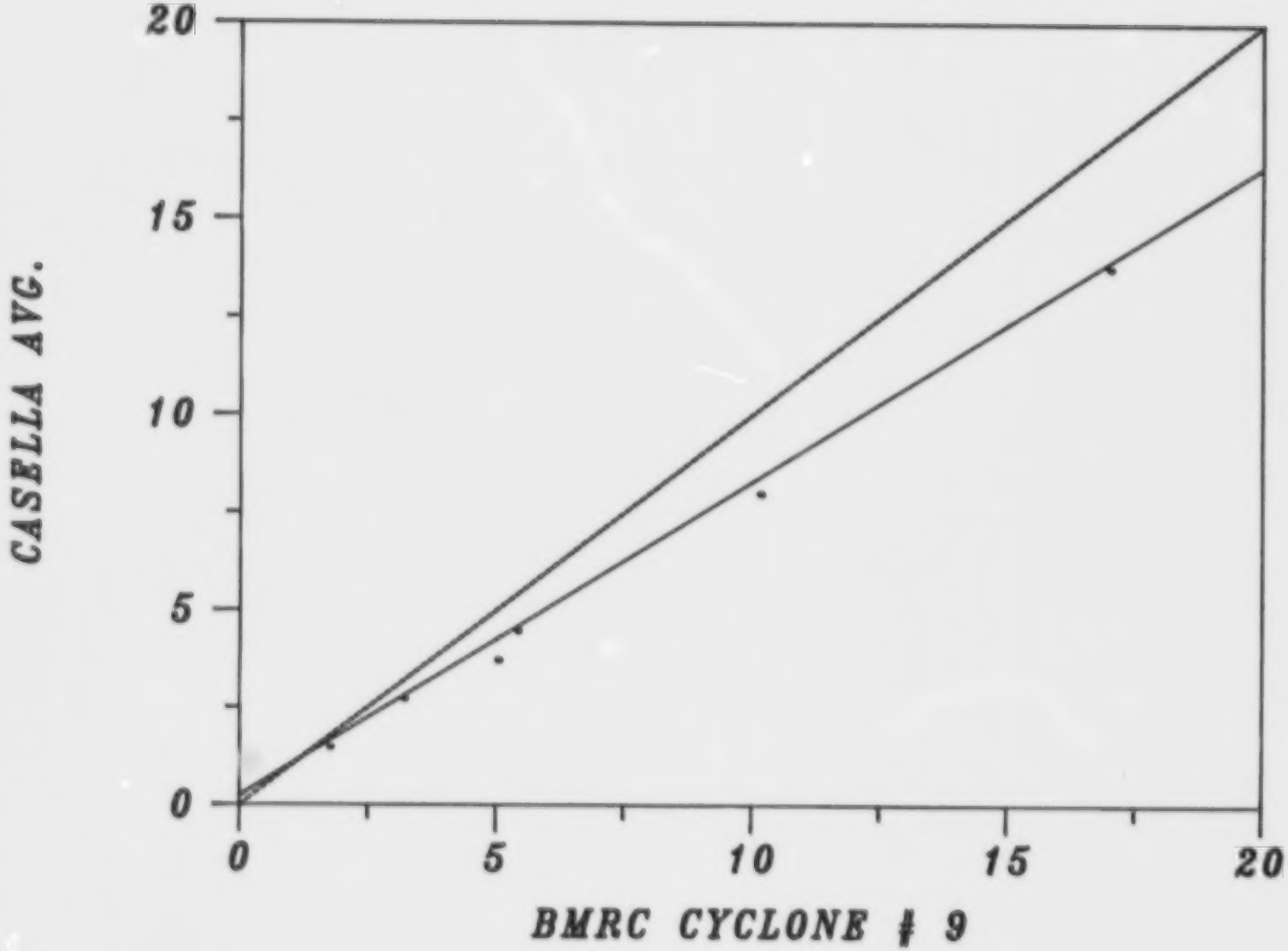

20
15
10
5
0
0
5
10
15
20
CASELLA AVG.
BMRC CYCLONE # 4

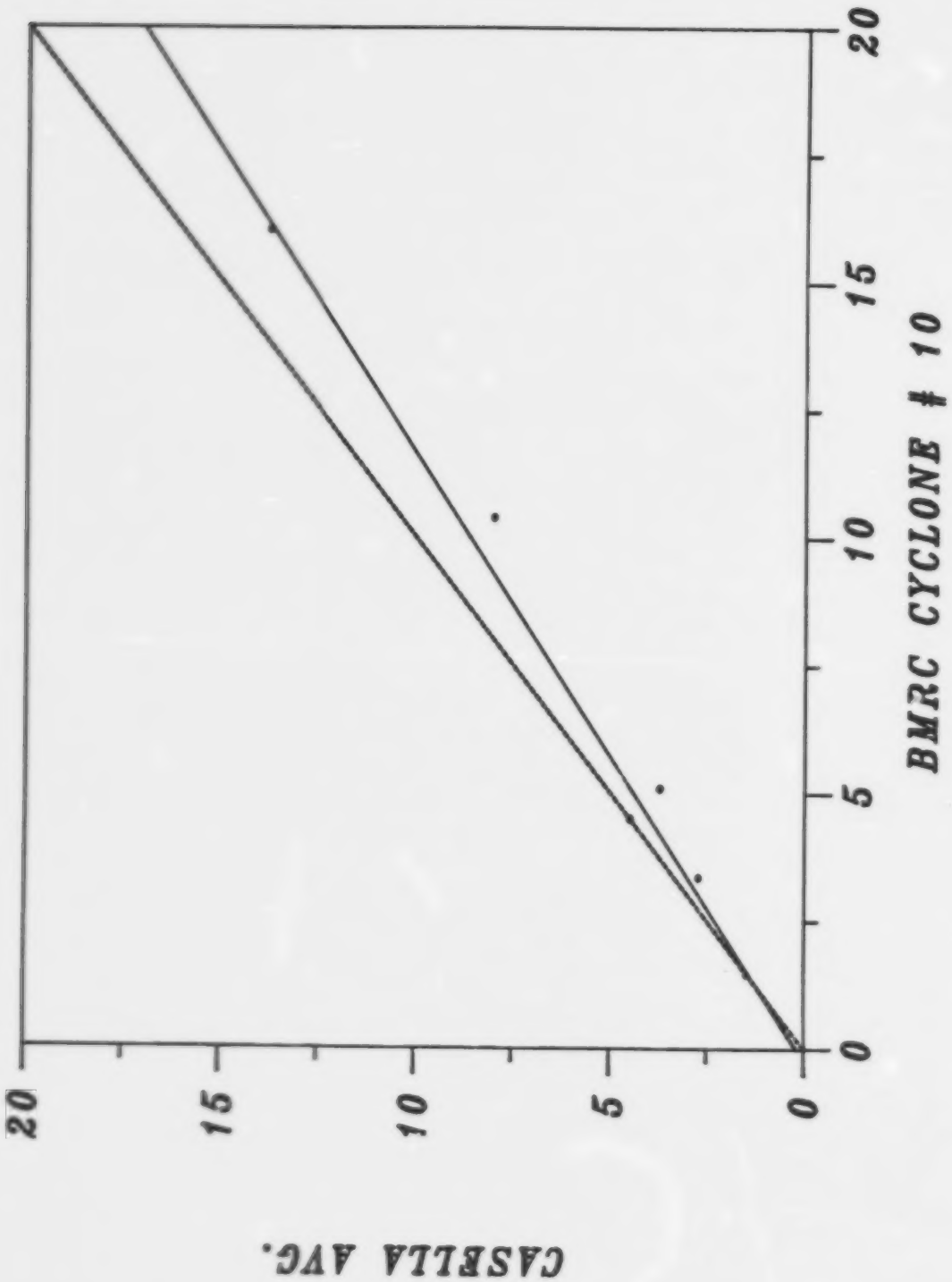

BMRC CYCLONE # 5
CASELLA AVG.
0
5
10
15
20

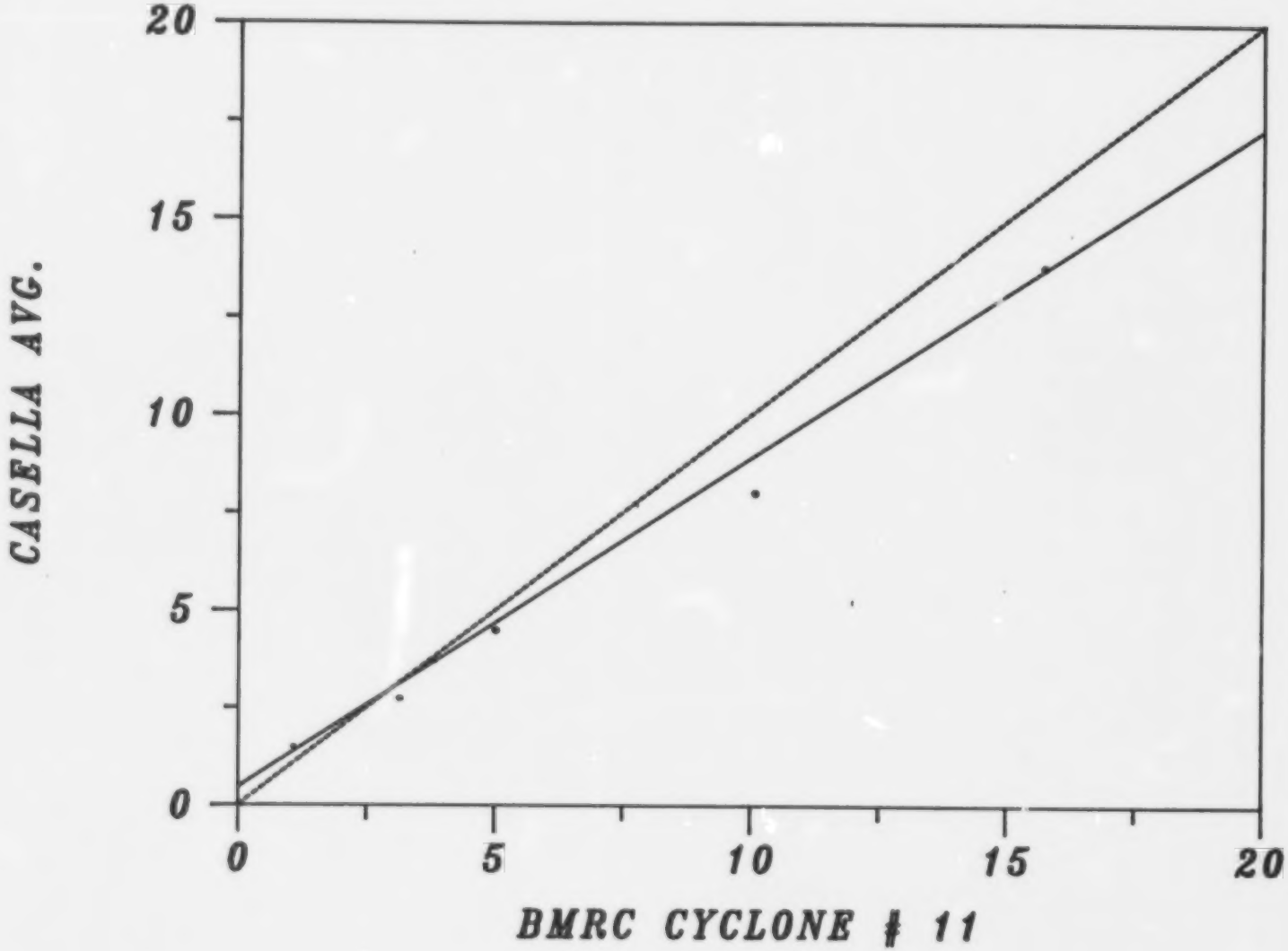

20
15
10
5
0
CASELLA AVG.
0
5
10
15
20
BMRC CYCLONE # 6

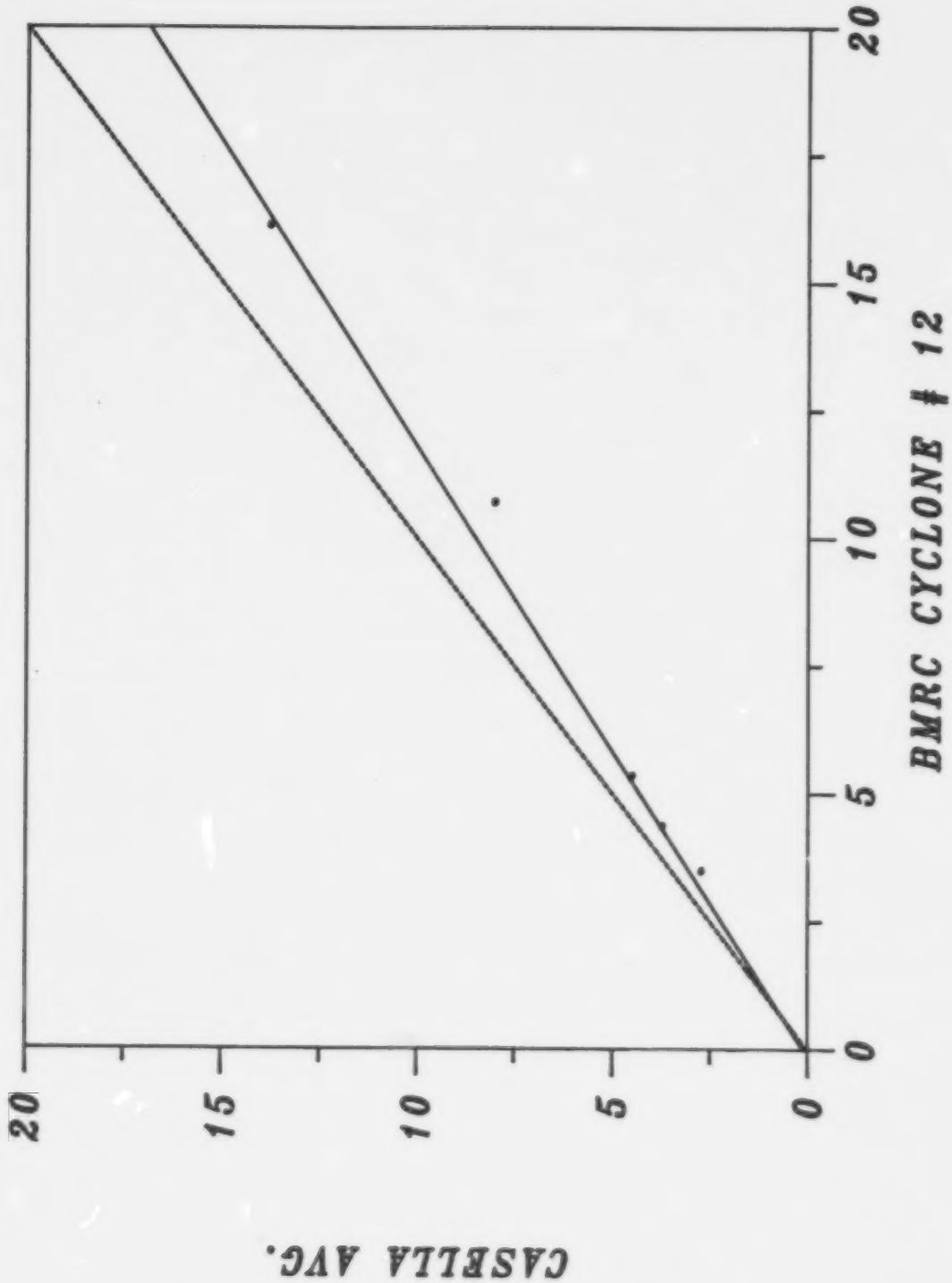

BMRC CYCLONE # 7
CASELLA AVG.
0
5
10
15
20

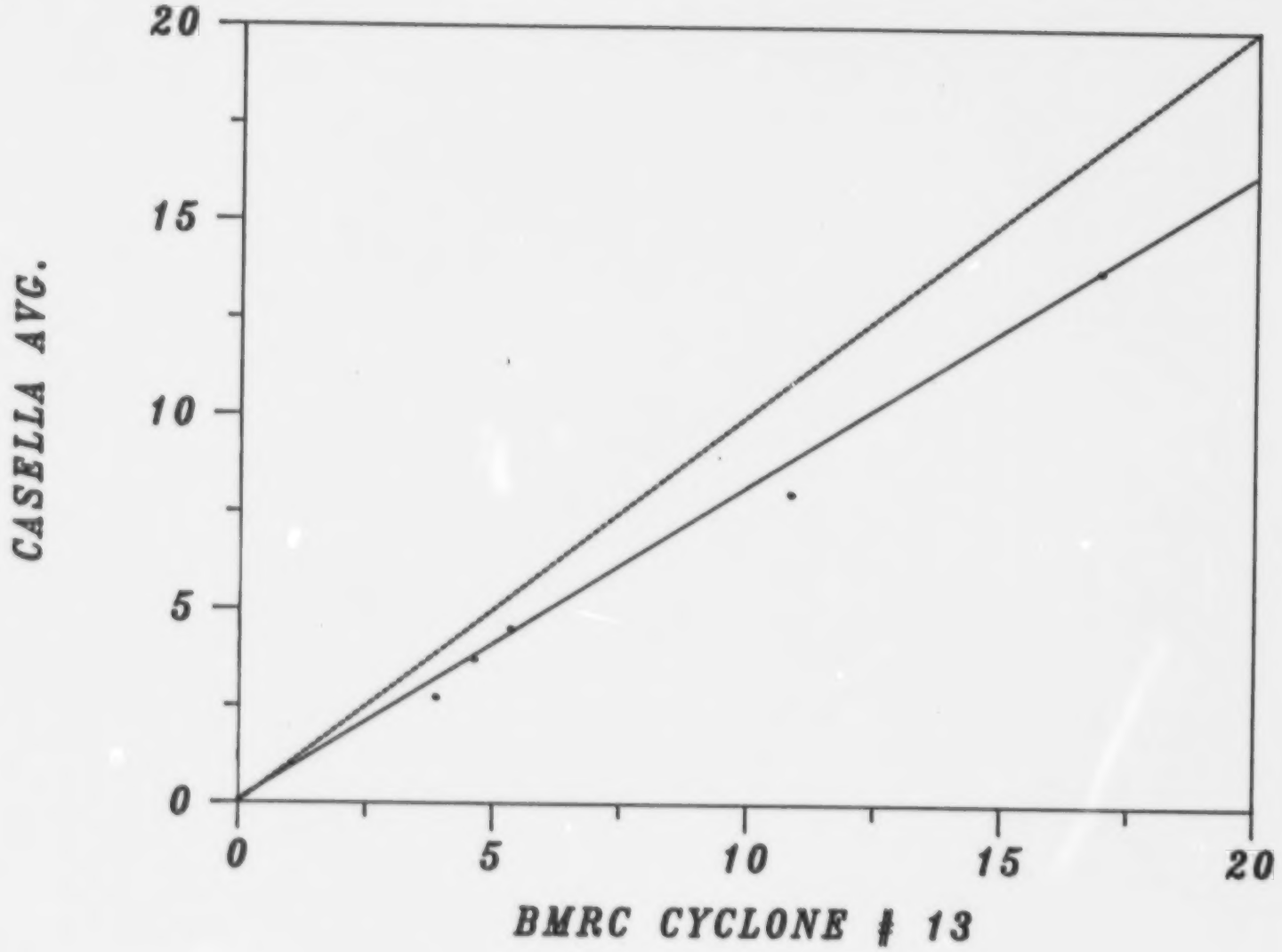

BMRC CYCLONE # 8
0
5
10
15
20
CASELLA AVG.
0
5
10
15
20


20
15
10
5
0
CASELLA AVG.
0
5
10
15
20
BMRC CYCLONE # 9

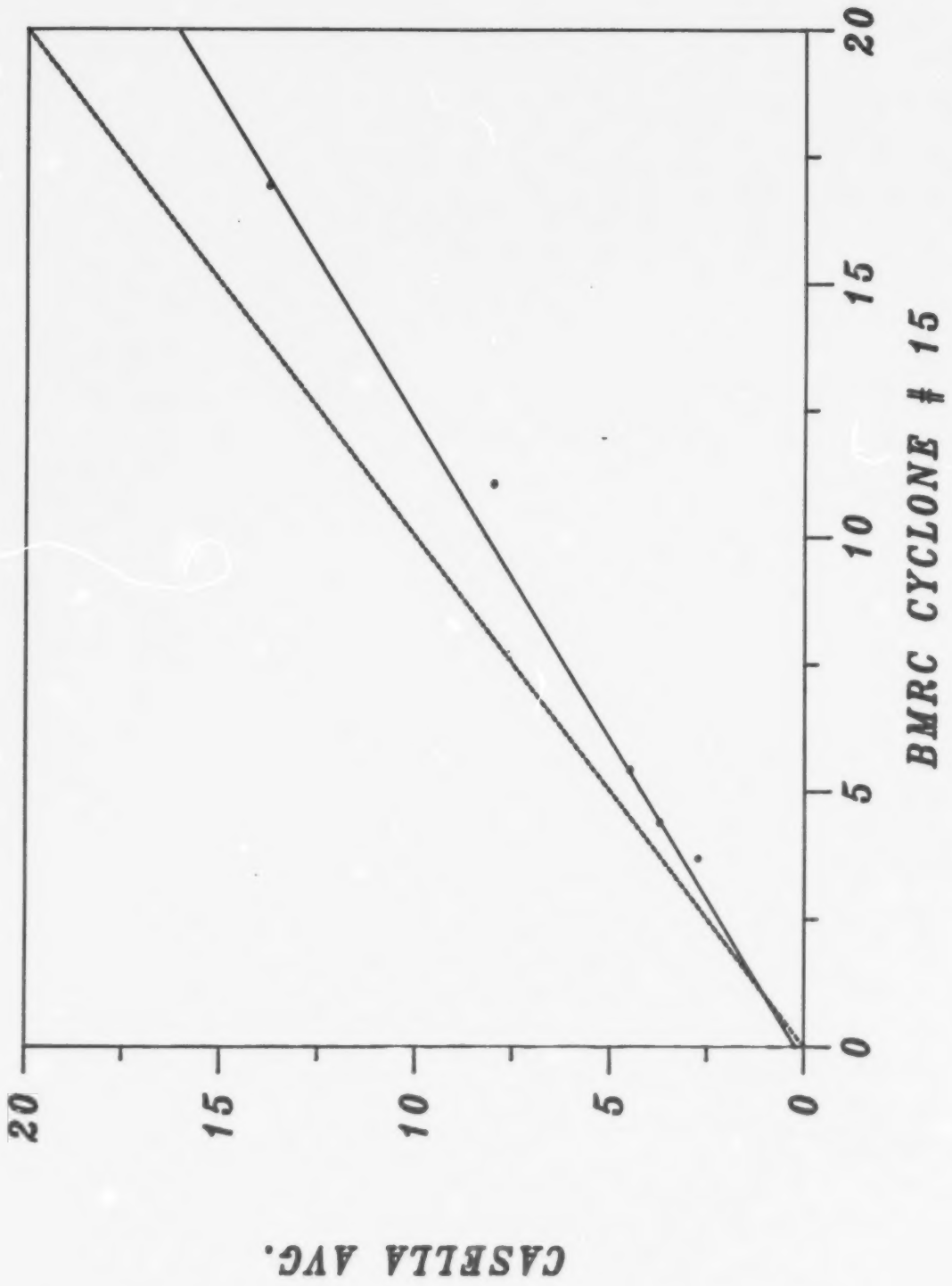

CASELLA AVG.
0
5
10
15
20
BMRC CYCLONE # 10
0
5
10
15
20

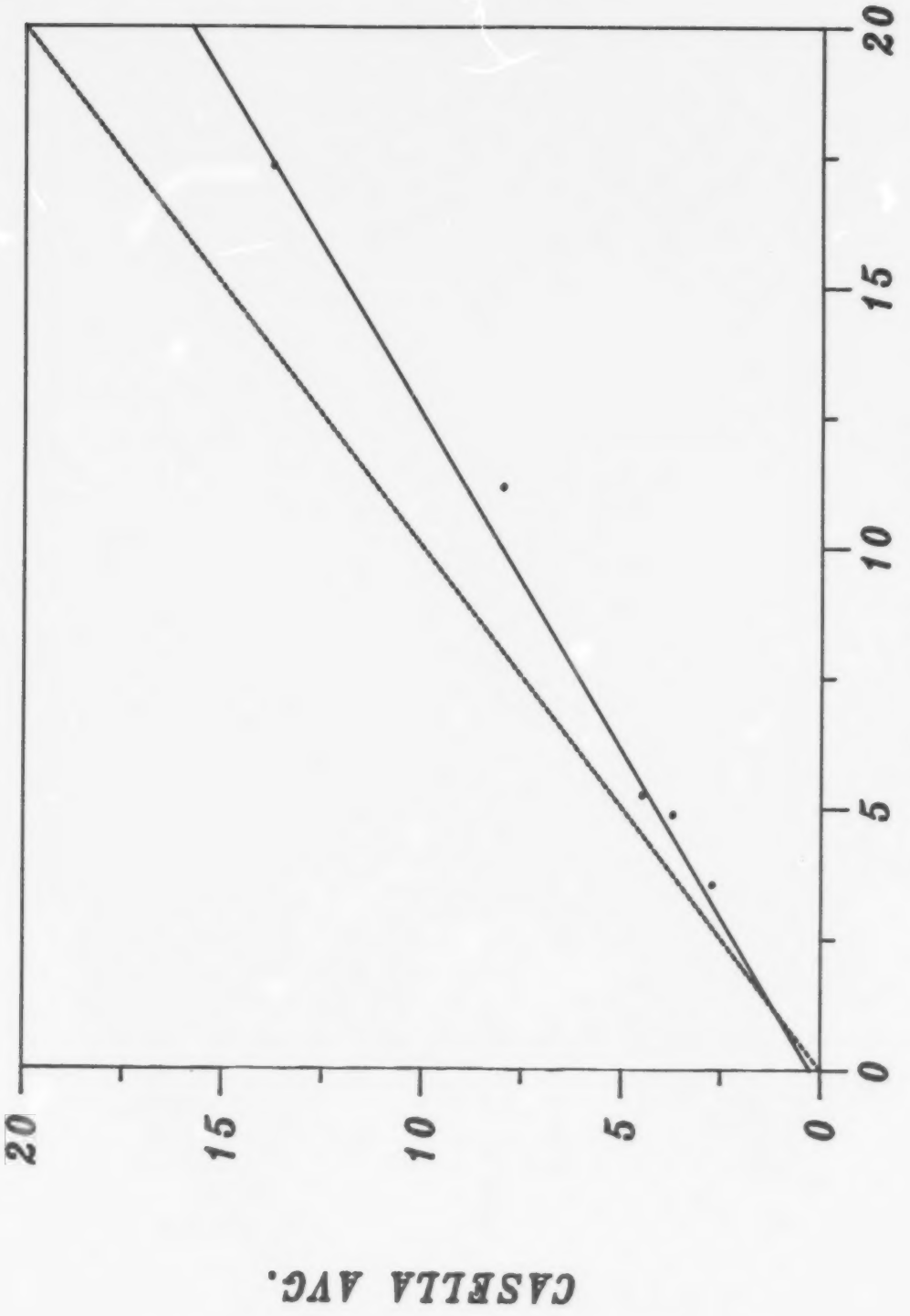

20
15
10
5
0
CASELLA AVG.
0
5
10
15
20
BMRC CYCLONE # 11

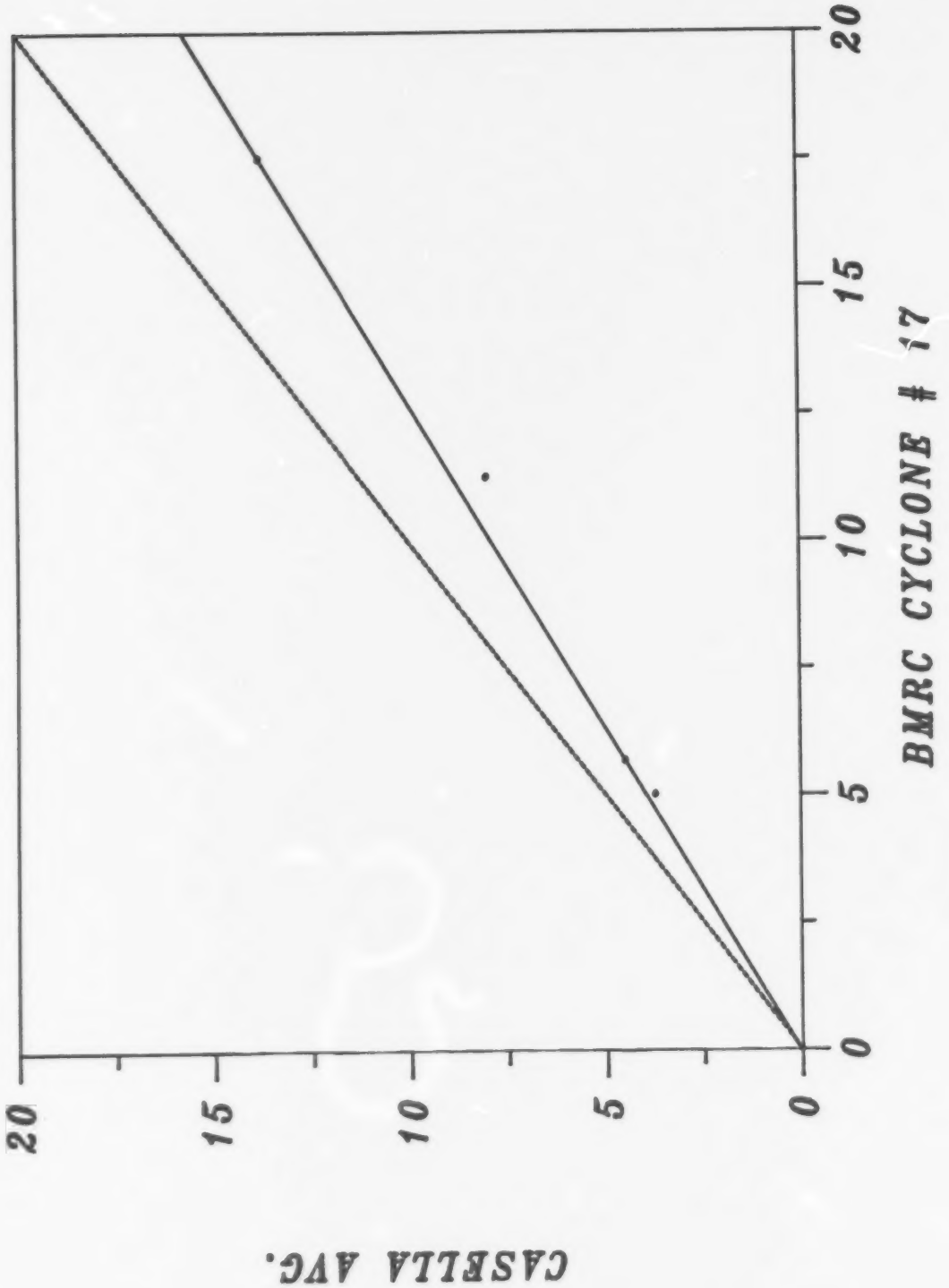

CASELLA AVG.
0
5
10
15
20
BMRC CYCLONE # 12
0
5
10
15
20

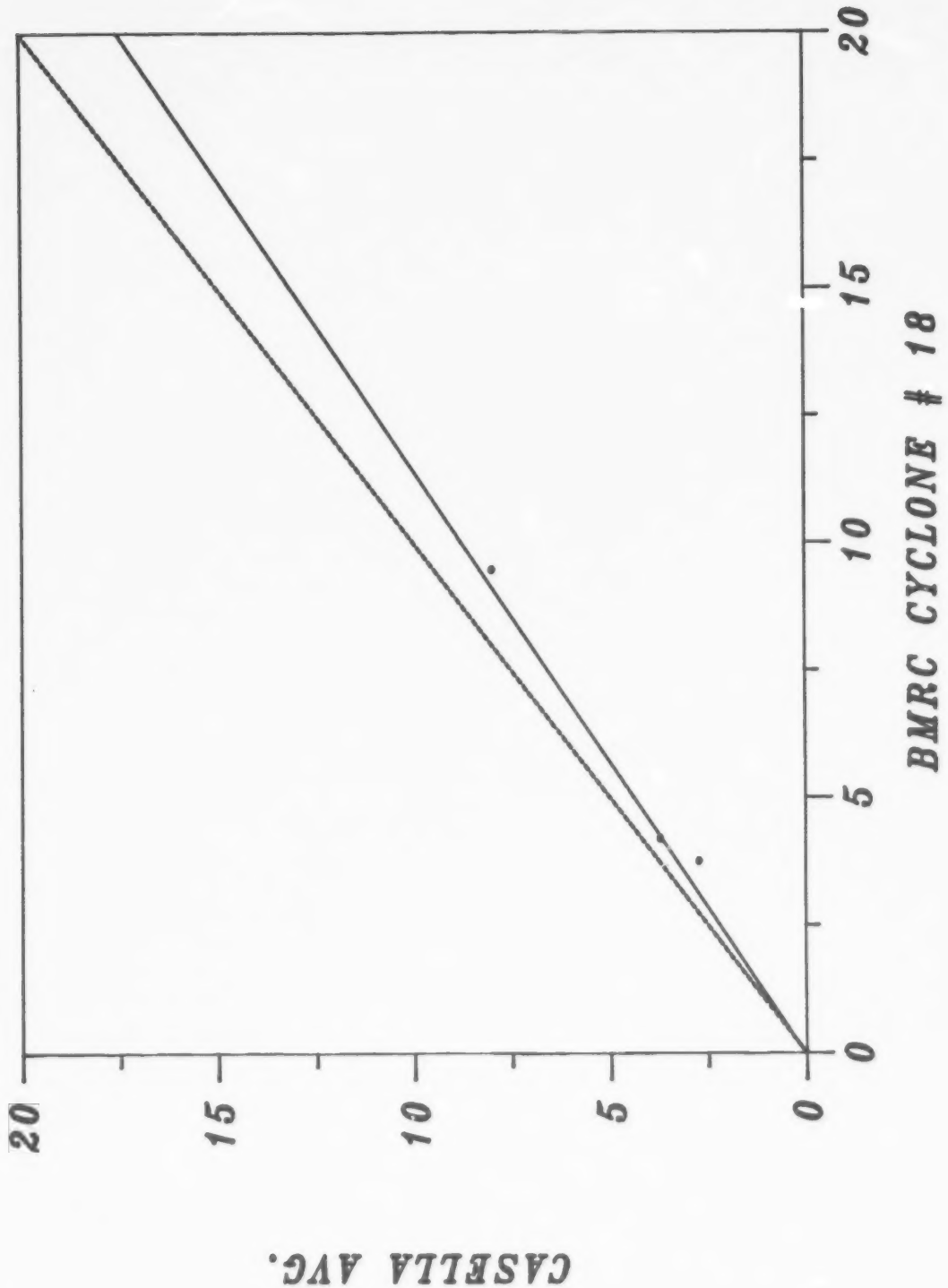

20
15
10
5
0
0
5
10
15
20
CASELLA AVG.
BMRC CYCLONE # 13

BMRC CYCLONE # 14
0
5
10
15
20
CASELLA AVG.


BMRC CYCLONE # 15
CASELLA AVG.
0
5
10
15
20

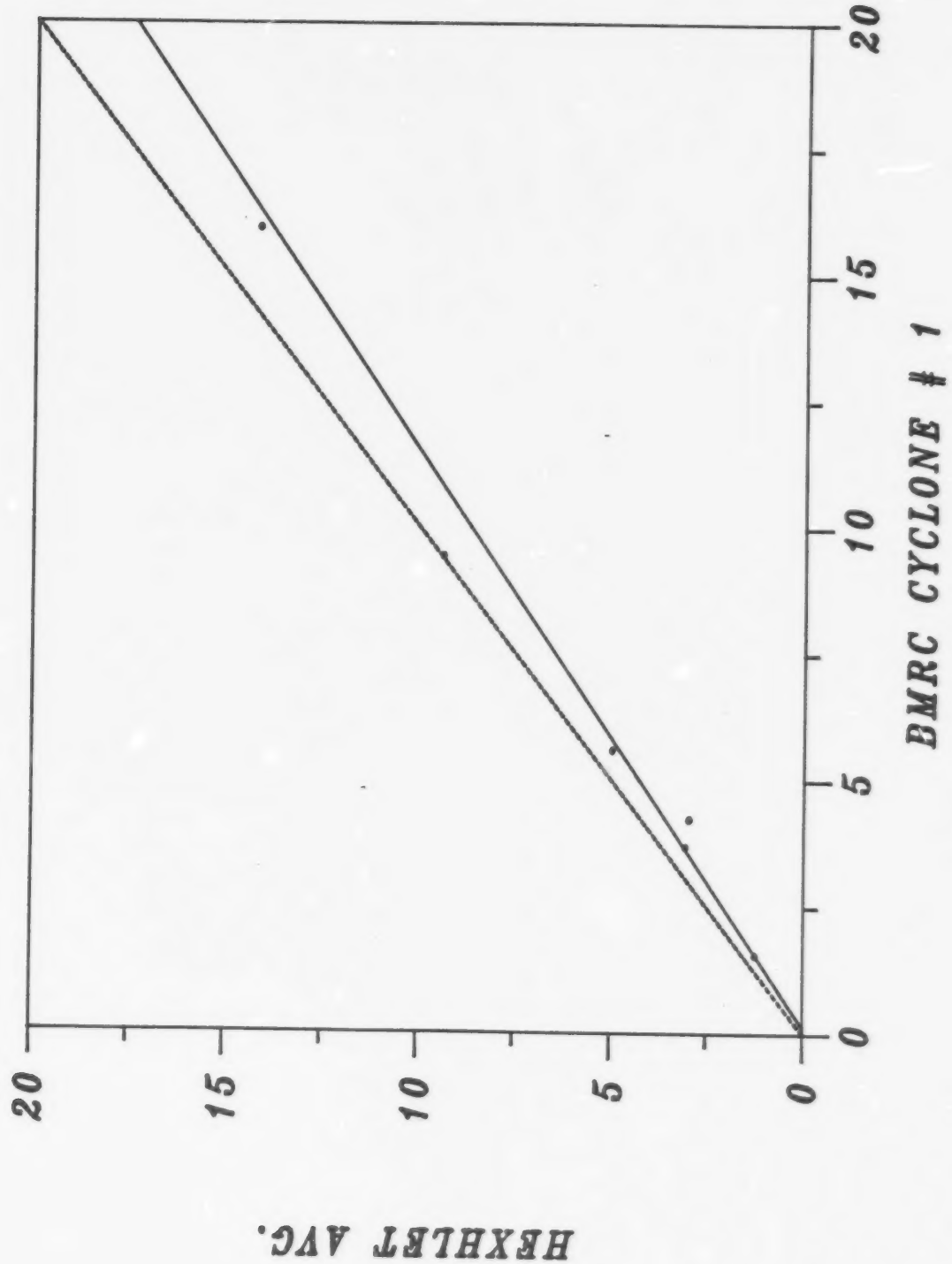

BMRC CYCLONE # 16
0
5
10
15
20
CASELLA AVG.
0
5
10
15
20

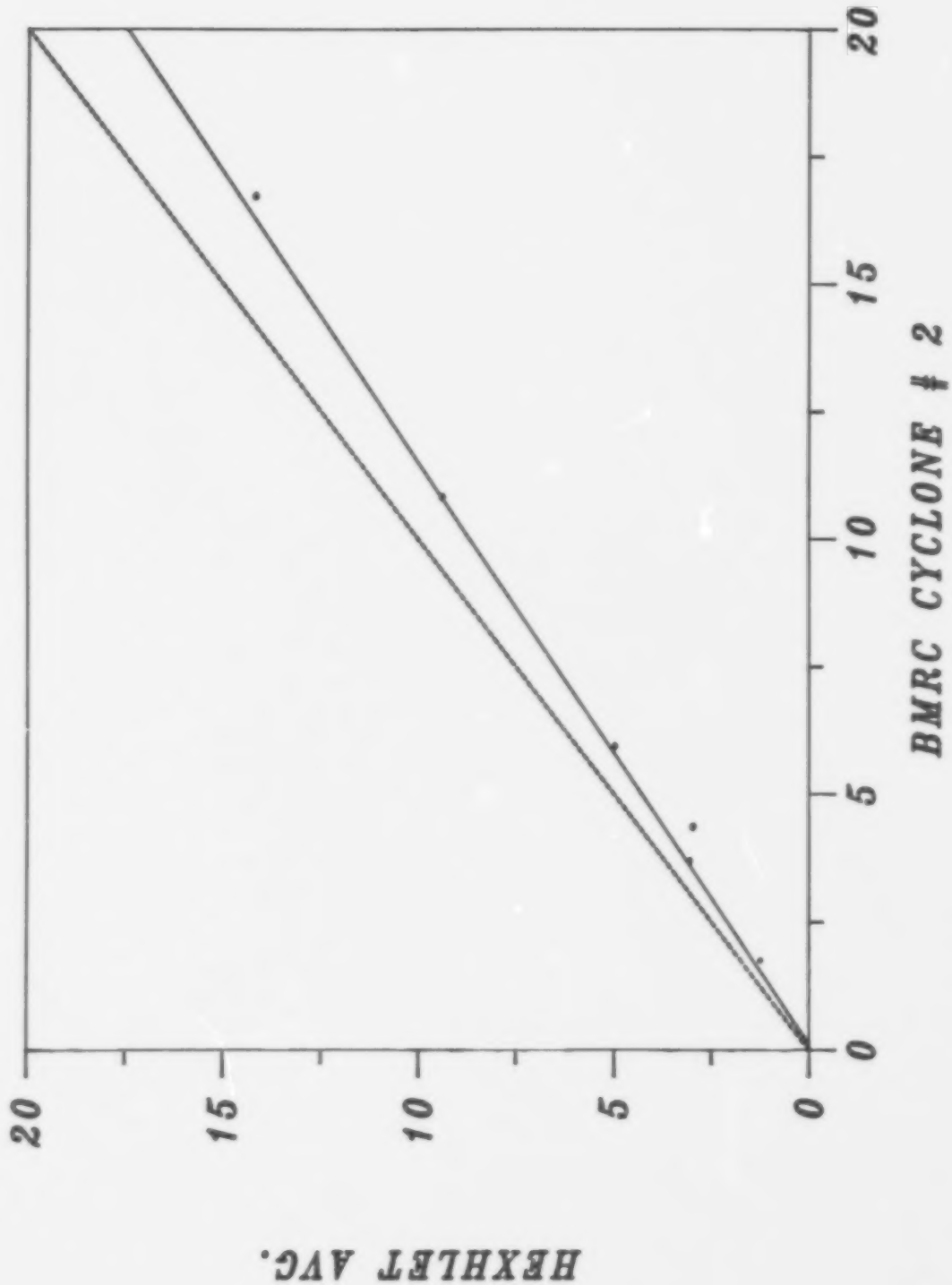

CASELLA AVG.
0
5
10
15
20
BMRC CYCLONE # 17
0
5
10
15
20

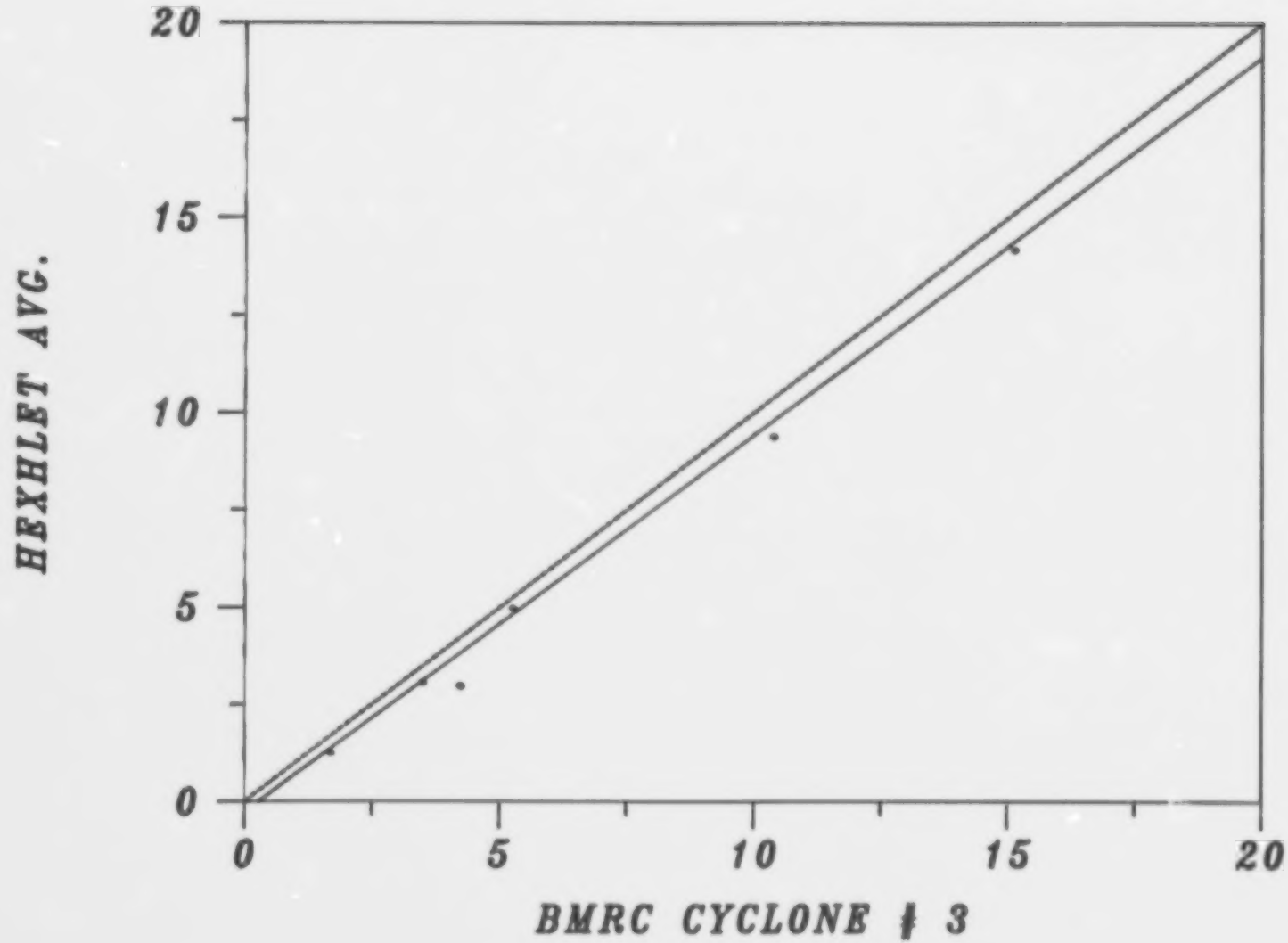

BMRC CYCLONE # 18
CASELLA AVG.
0
5
10
15
20

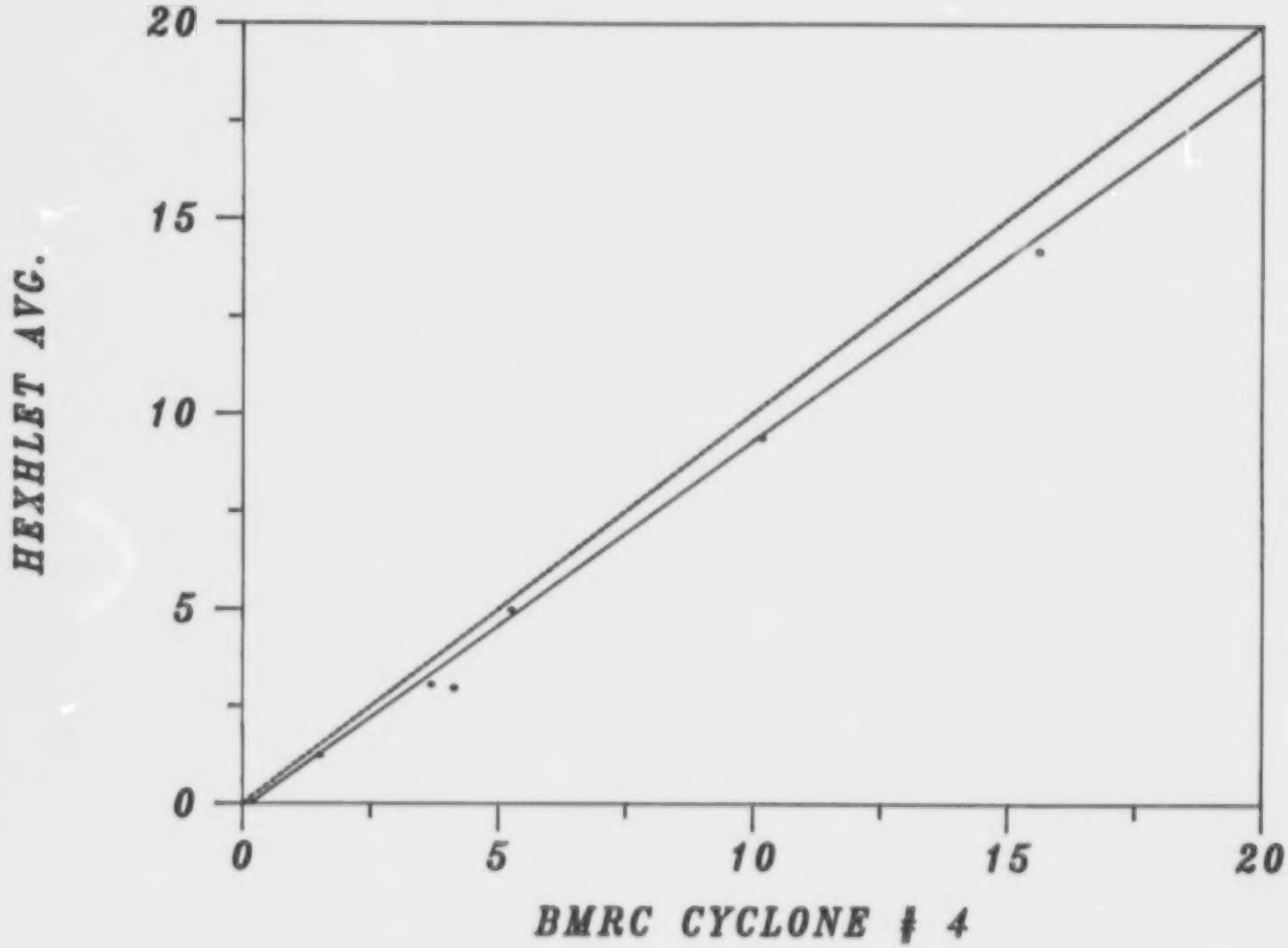
APPENDIX E

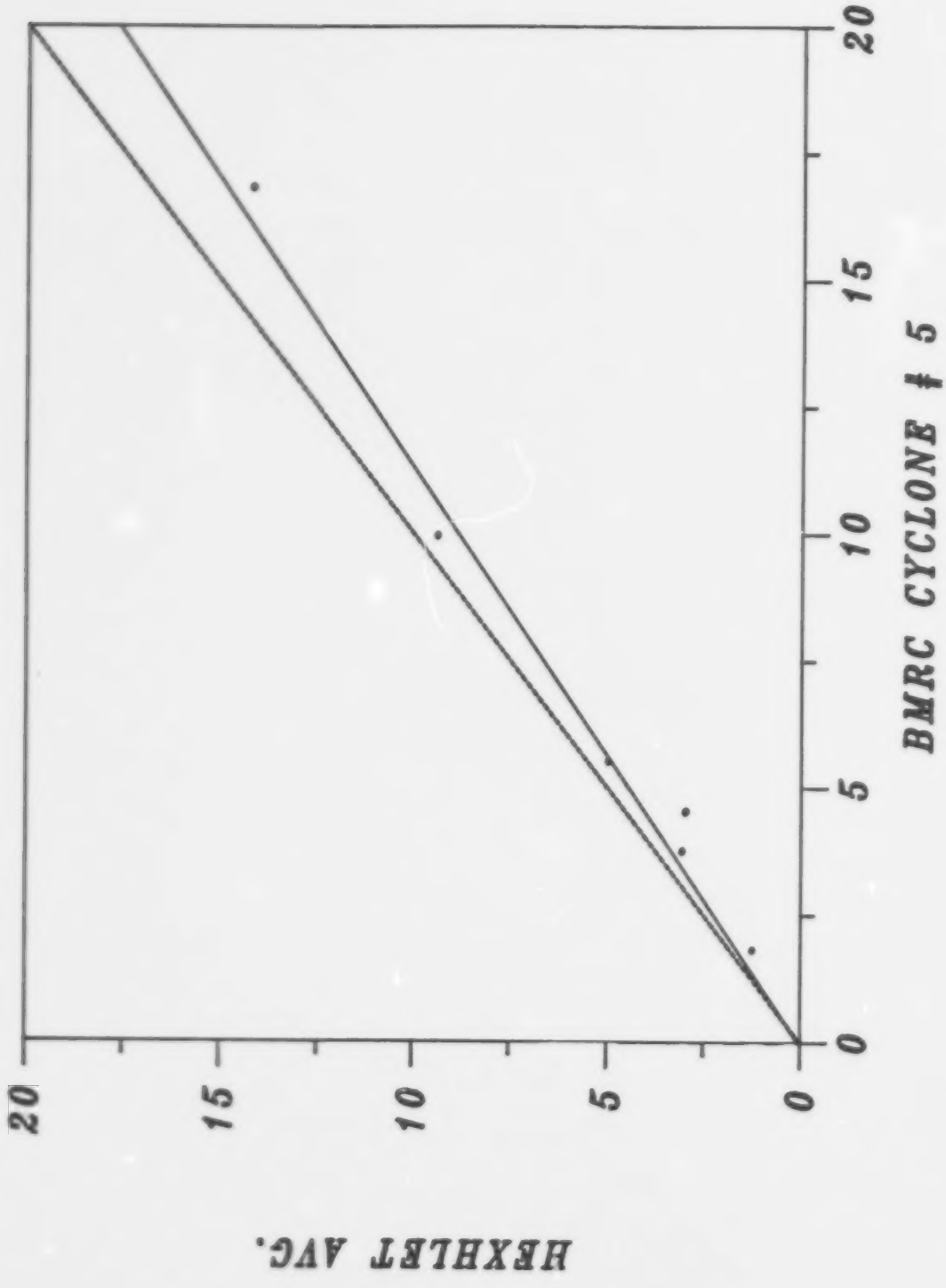
BMRC Cyclones vs Hexhlet Average

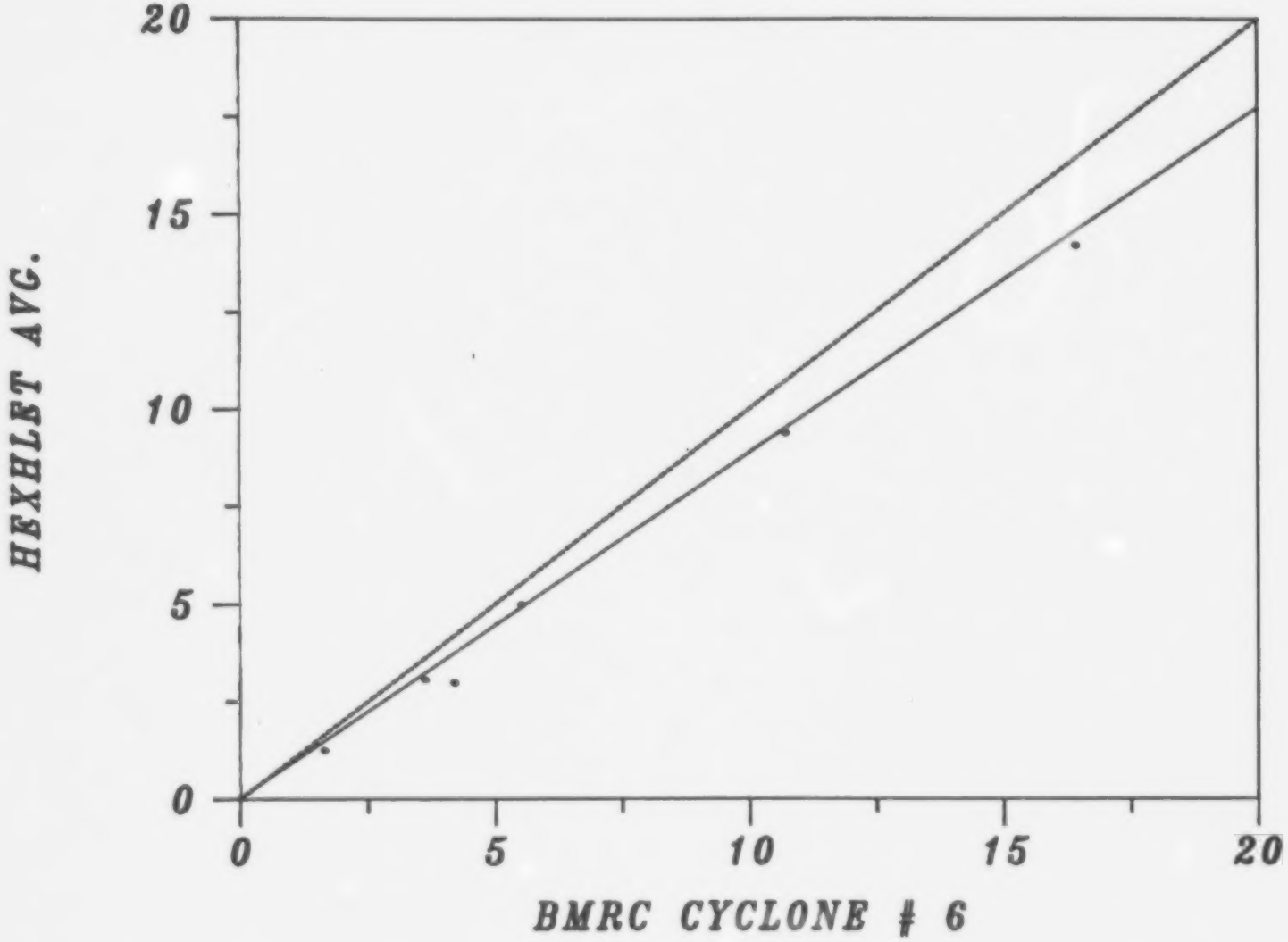

BMRC CYCLONE # 1
HEXHLET AVG.
0
5
10
15
20

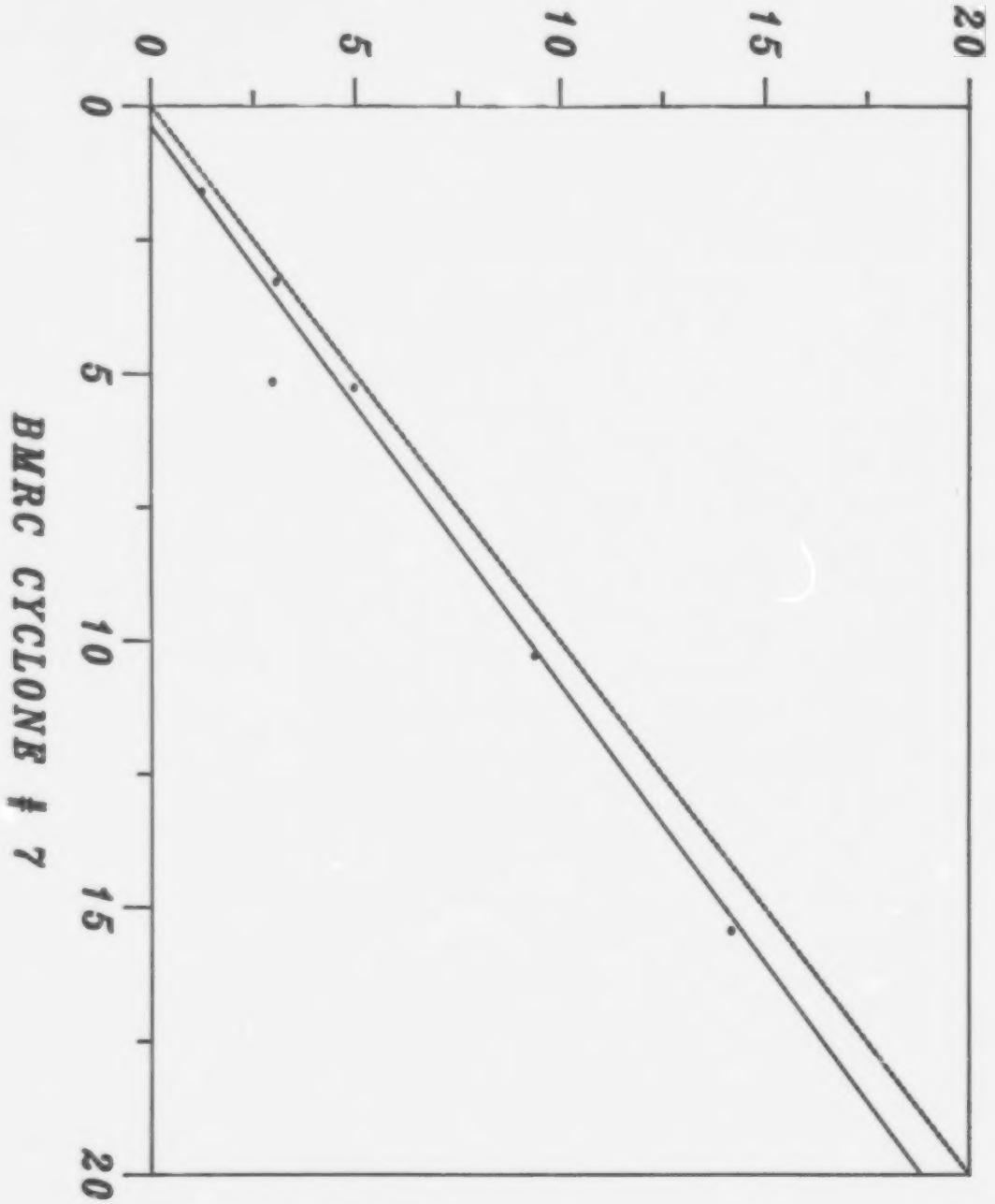

HEXHLET AVG.
0
5
10
15
20
BMRC CYCLONE # 2
0
5
10
15
20

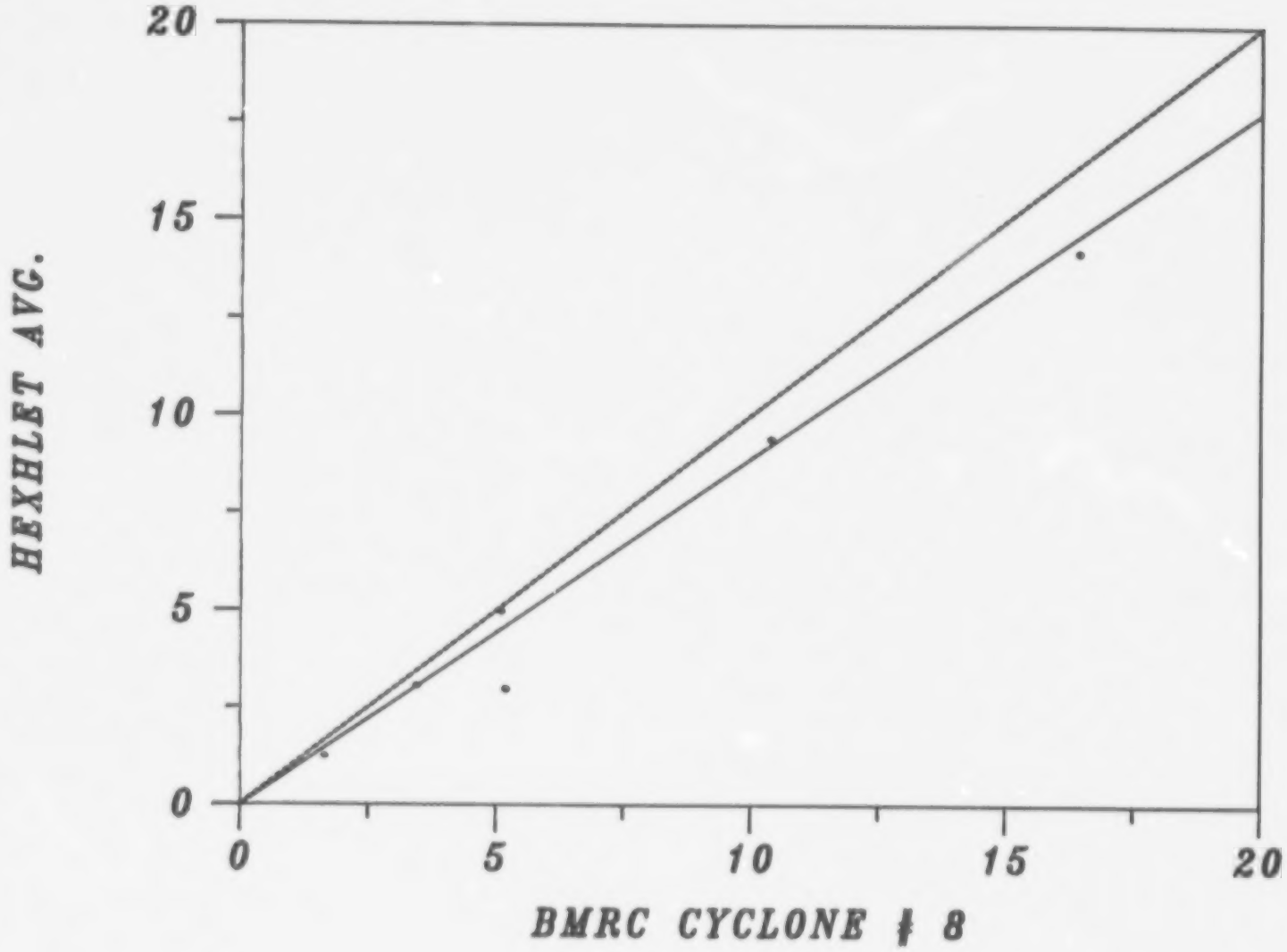

HEXHLET AVG.
20
15
10
5
0
0
5
10
15
20
BMRC CYCLONE # 3

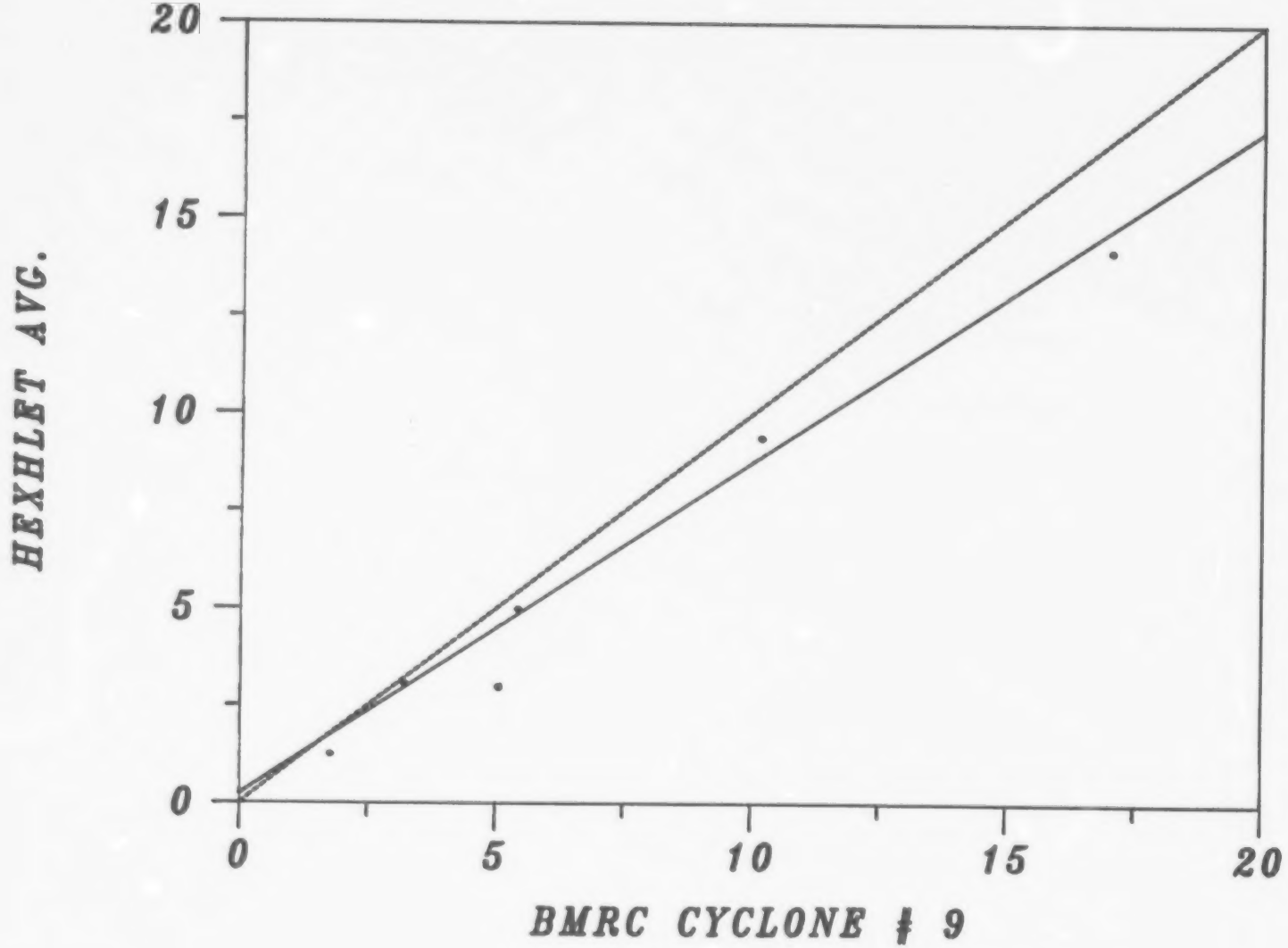

20
15
10
5
0
HEXHLET AVG.
0
5
10
15
20
BMRC CYCLONE # 4


BMRC CYCLONE # 5
HEXHLET AVG.
0
5
10
15
20


HEXHLET AVG.
20
15
10
5
0
0
5
10
15
20
BMRC CYCLONE # 6


HEXHLET AVG.
BMRC CYCLONE # 7
0
5
10
15
20
0
5
10
15
20


HEXHLET AVG.
20
15
10
5
0
0
5
10
15
20
BMRC CYCLONE # 8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HEXHLET AVG.
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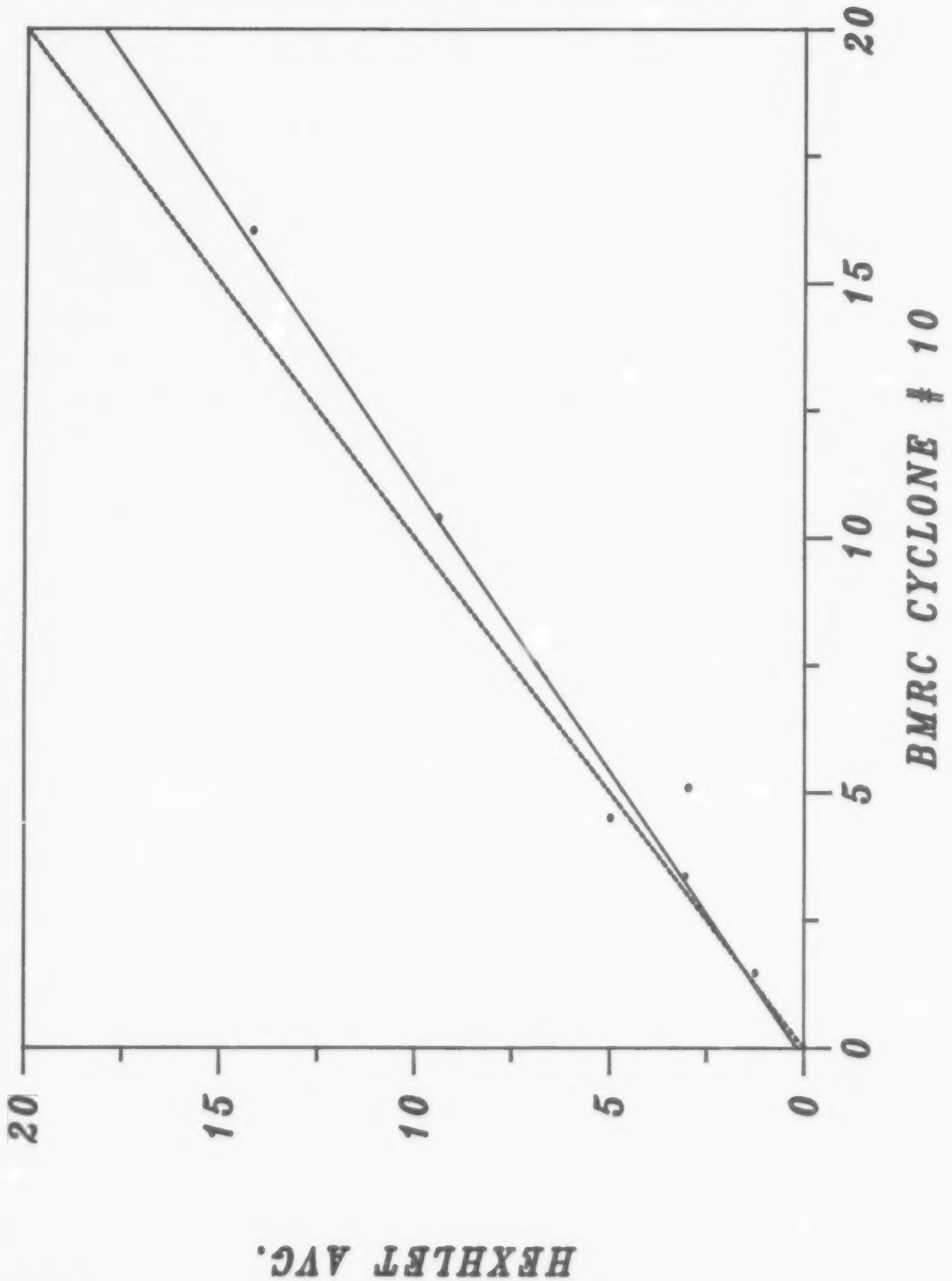
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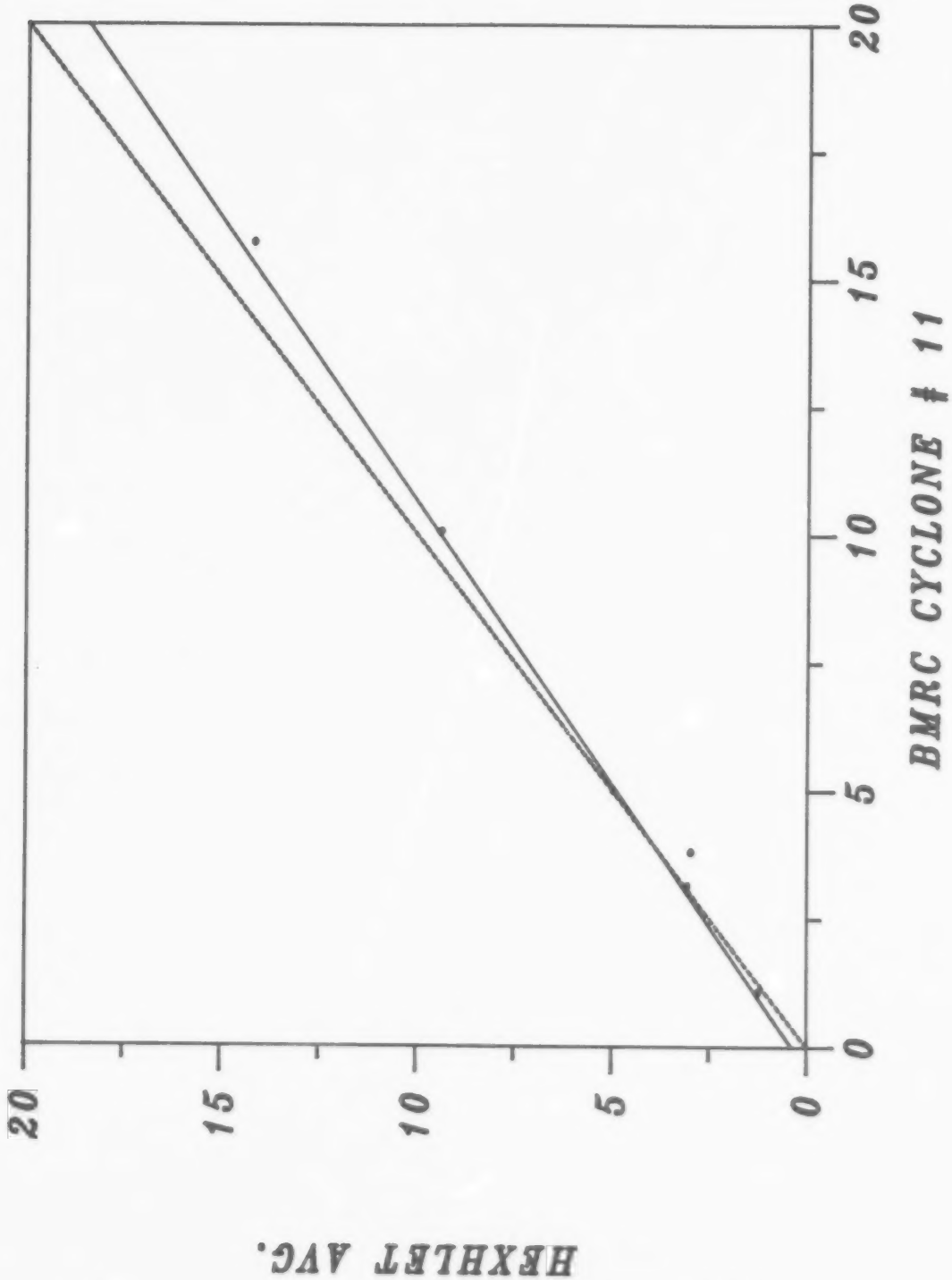
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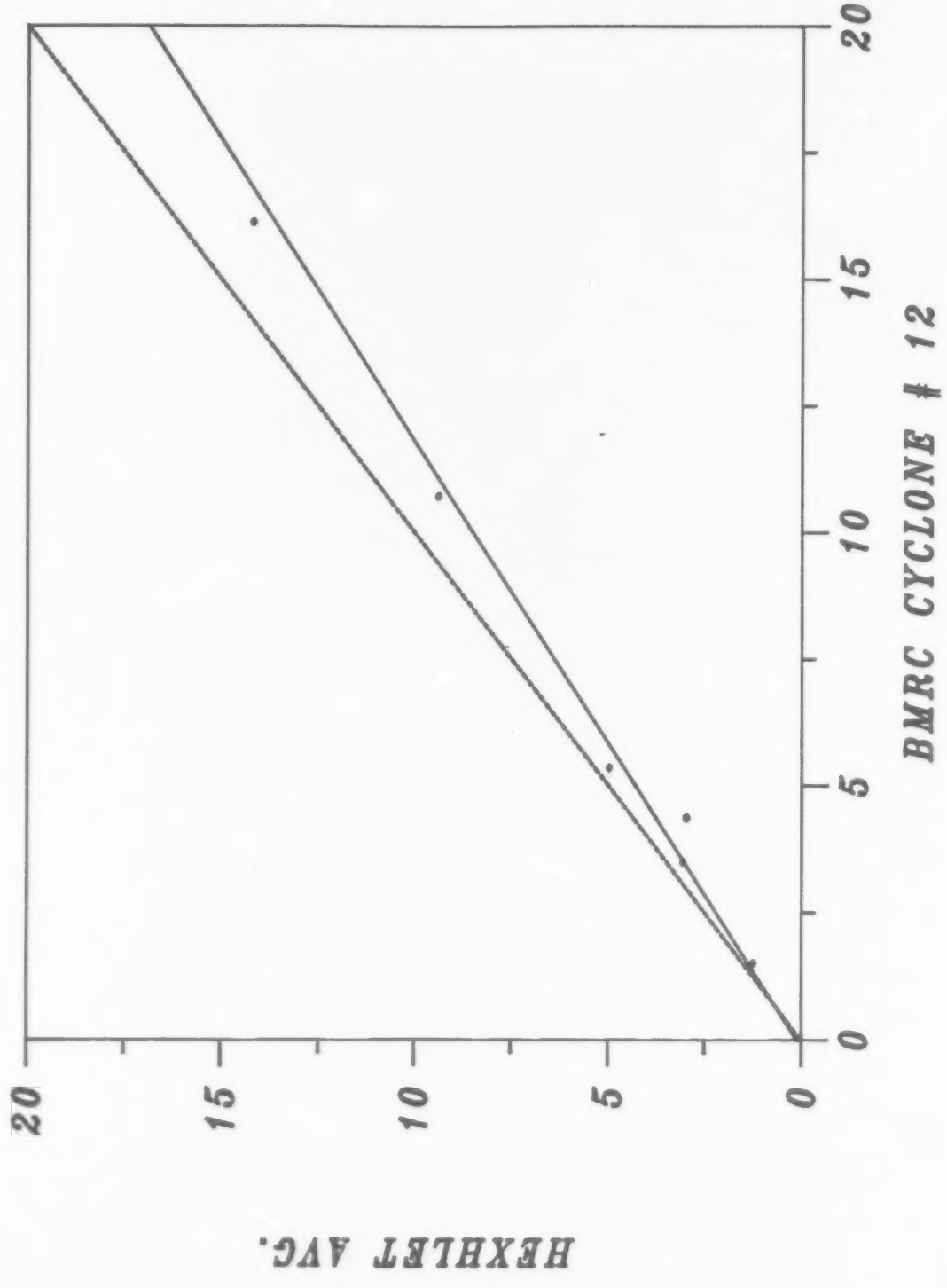
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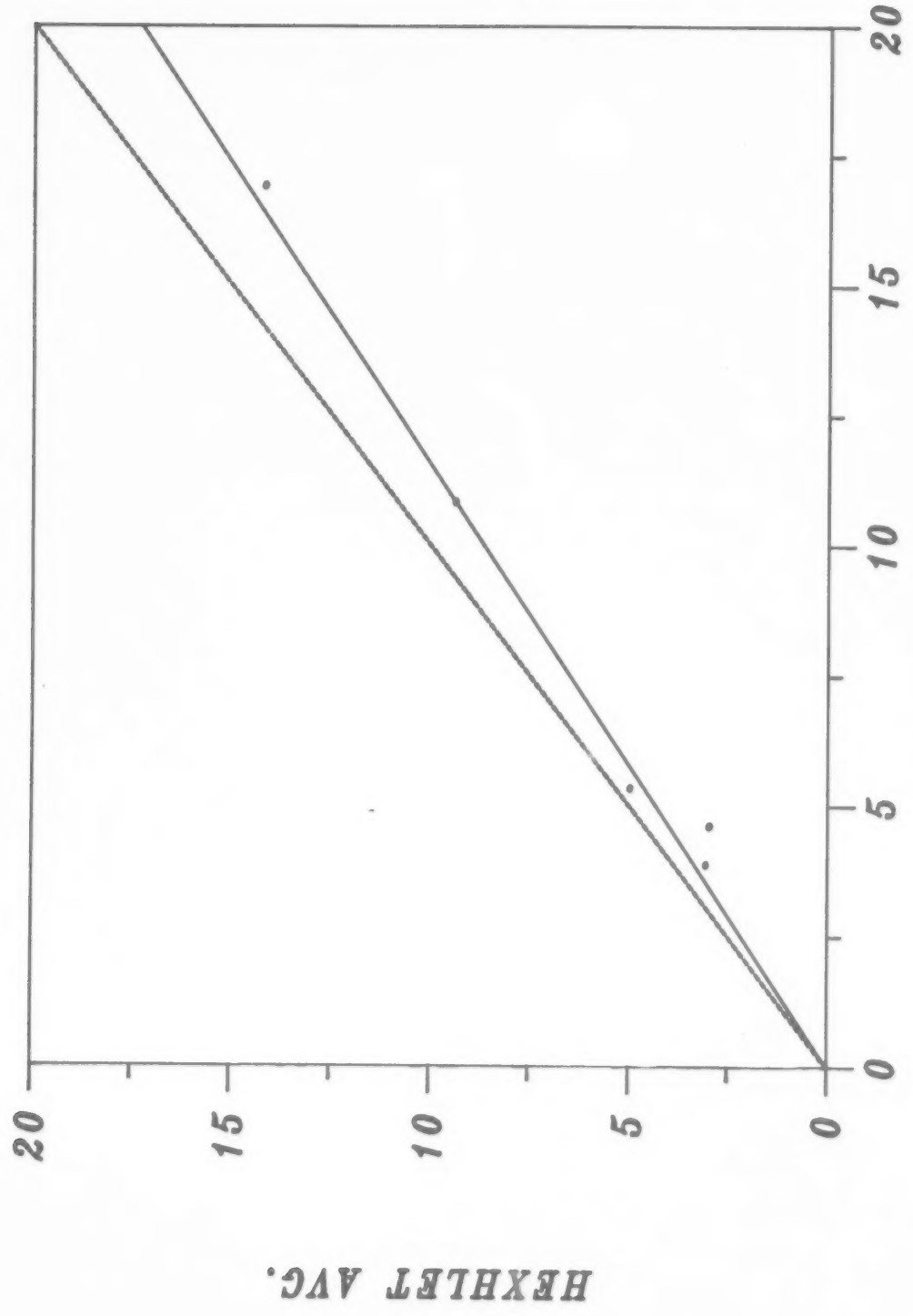
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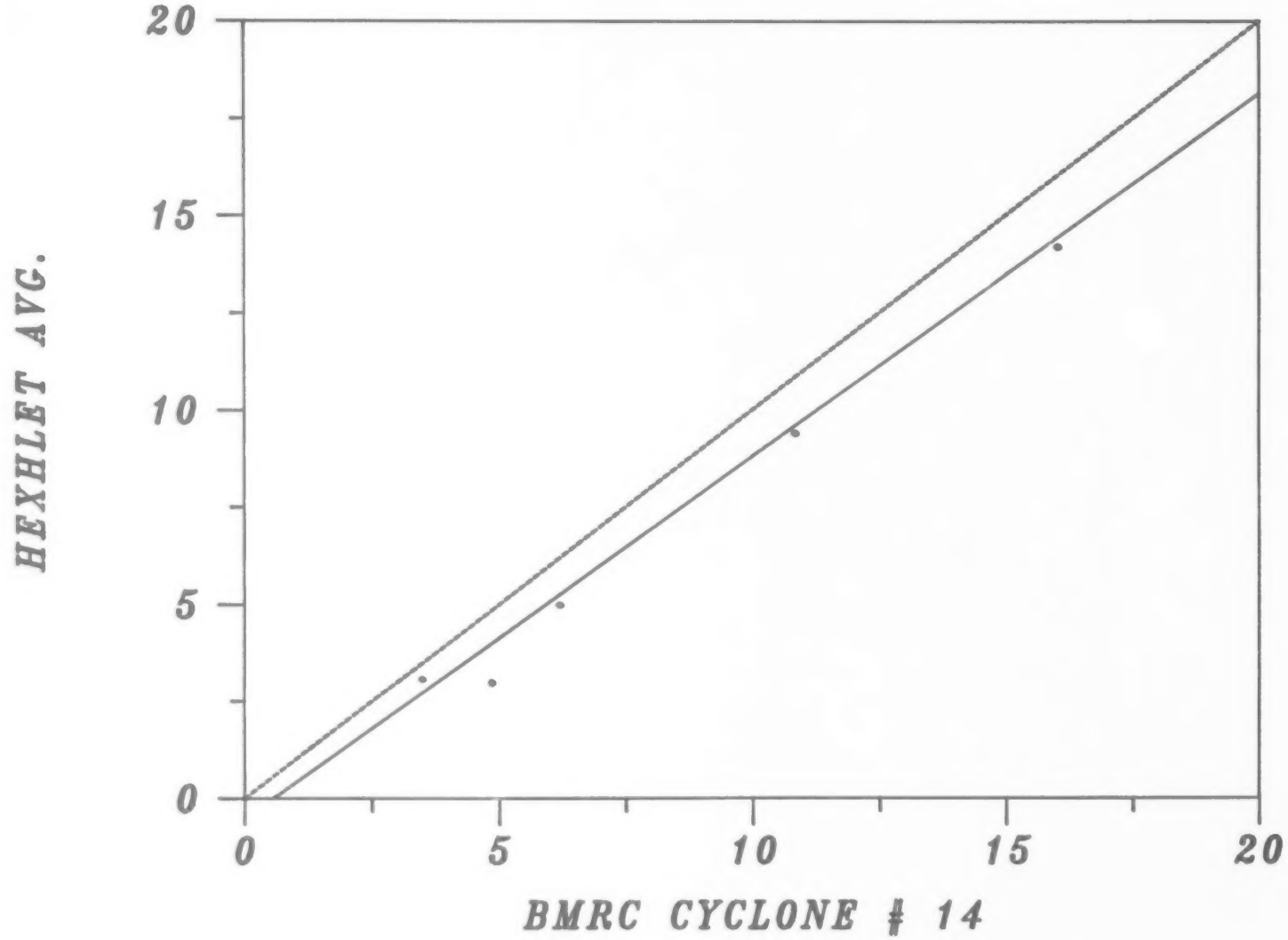
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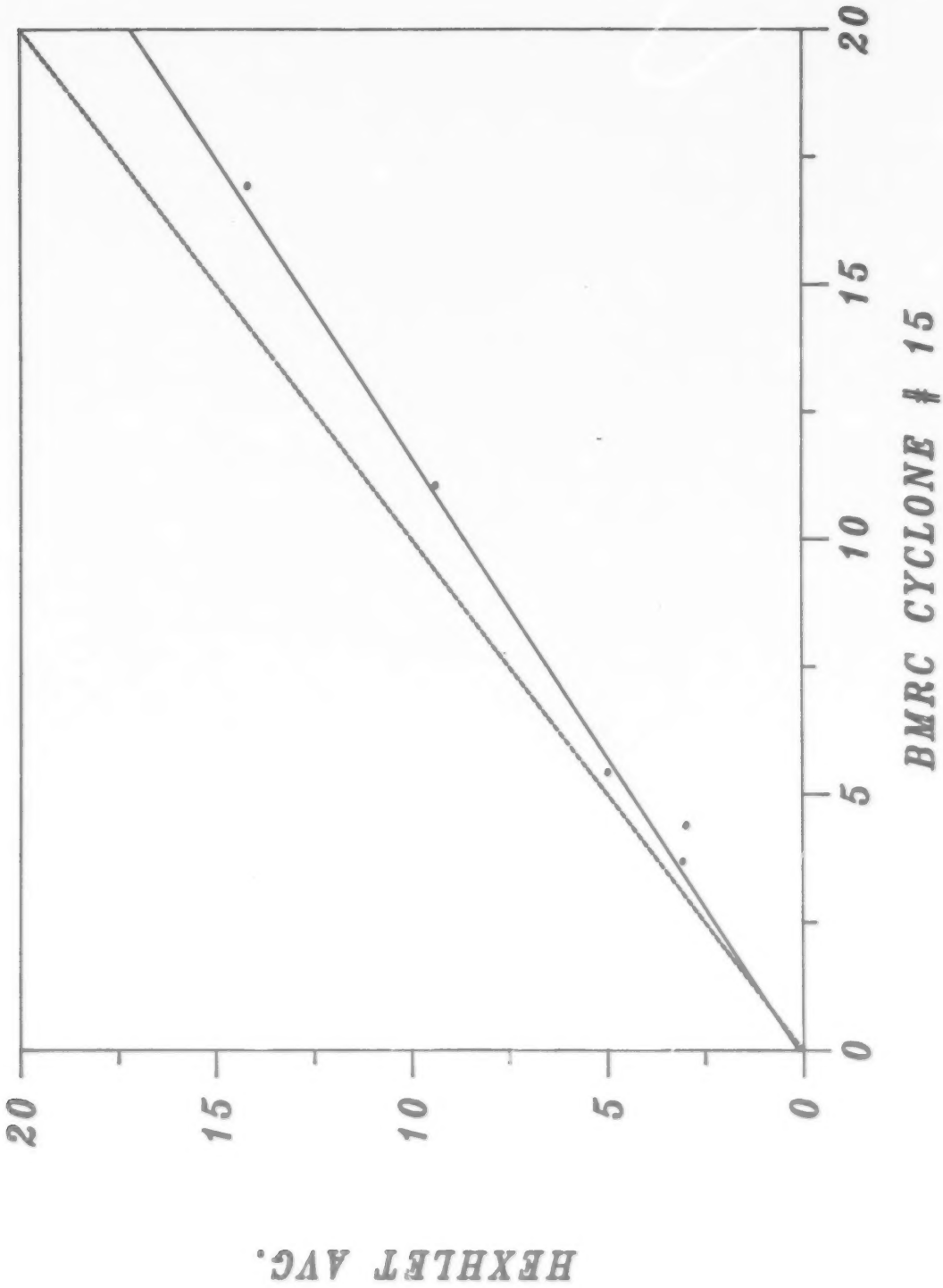
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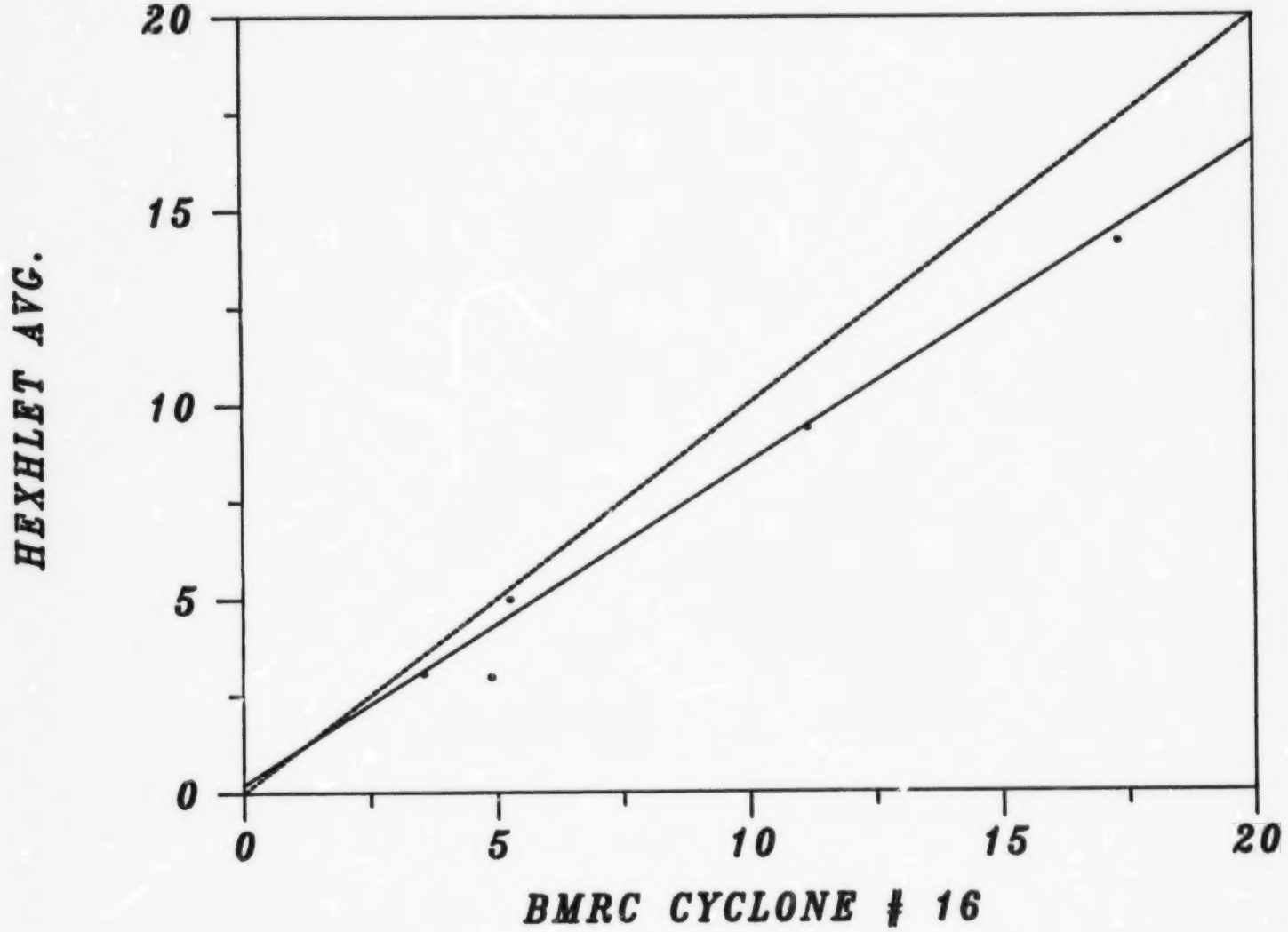
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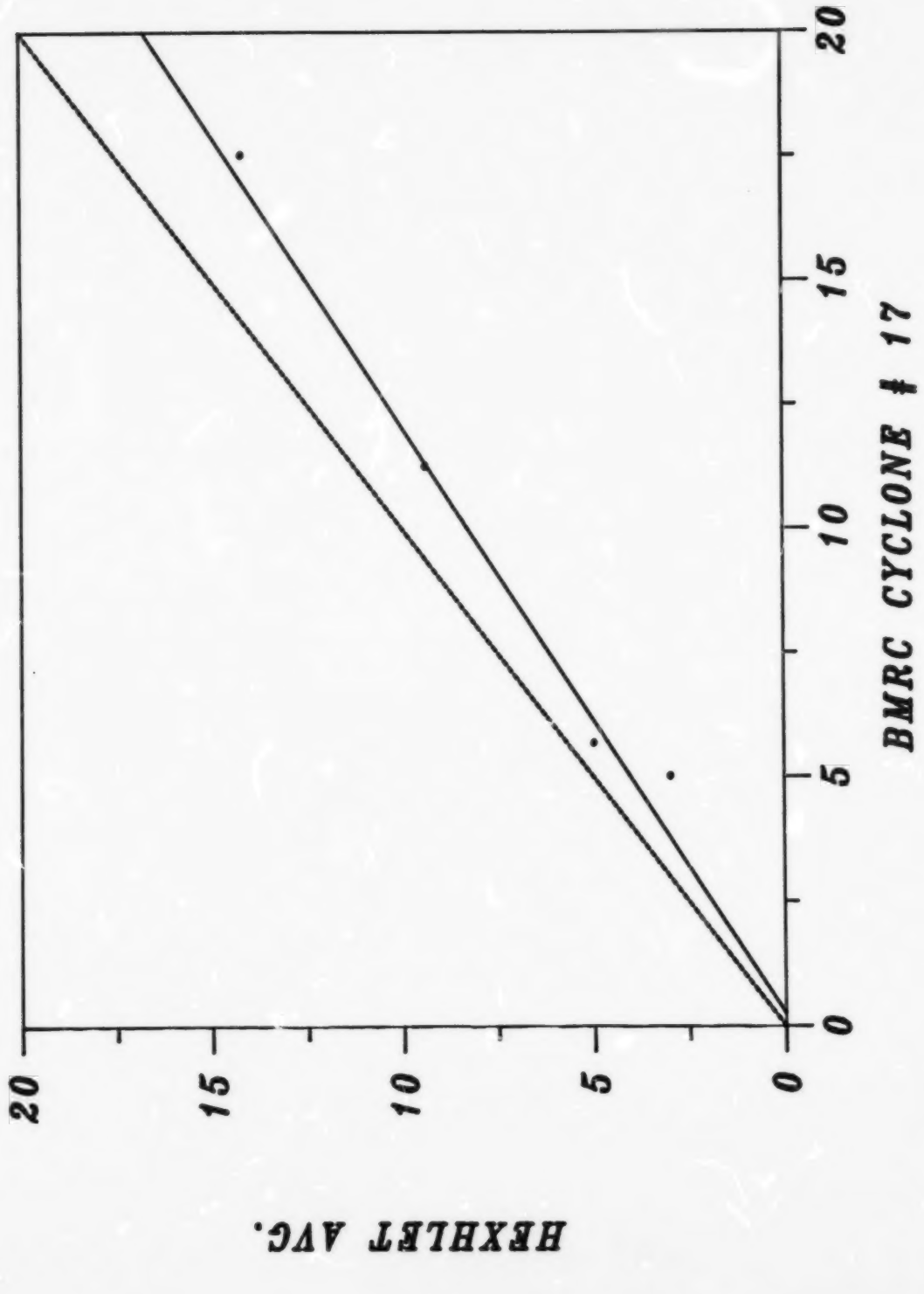
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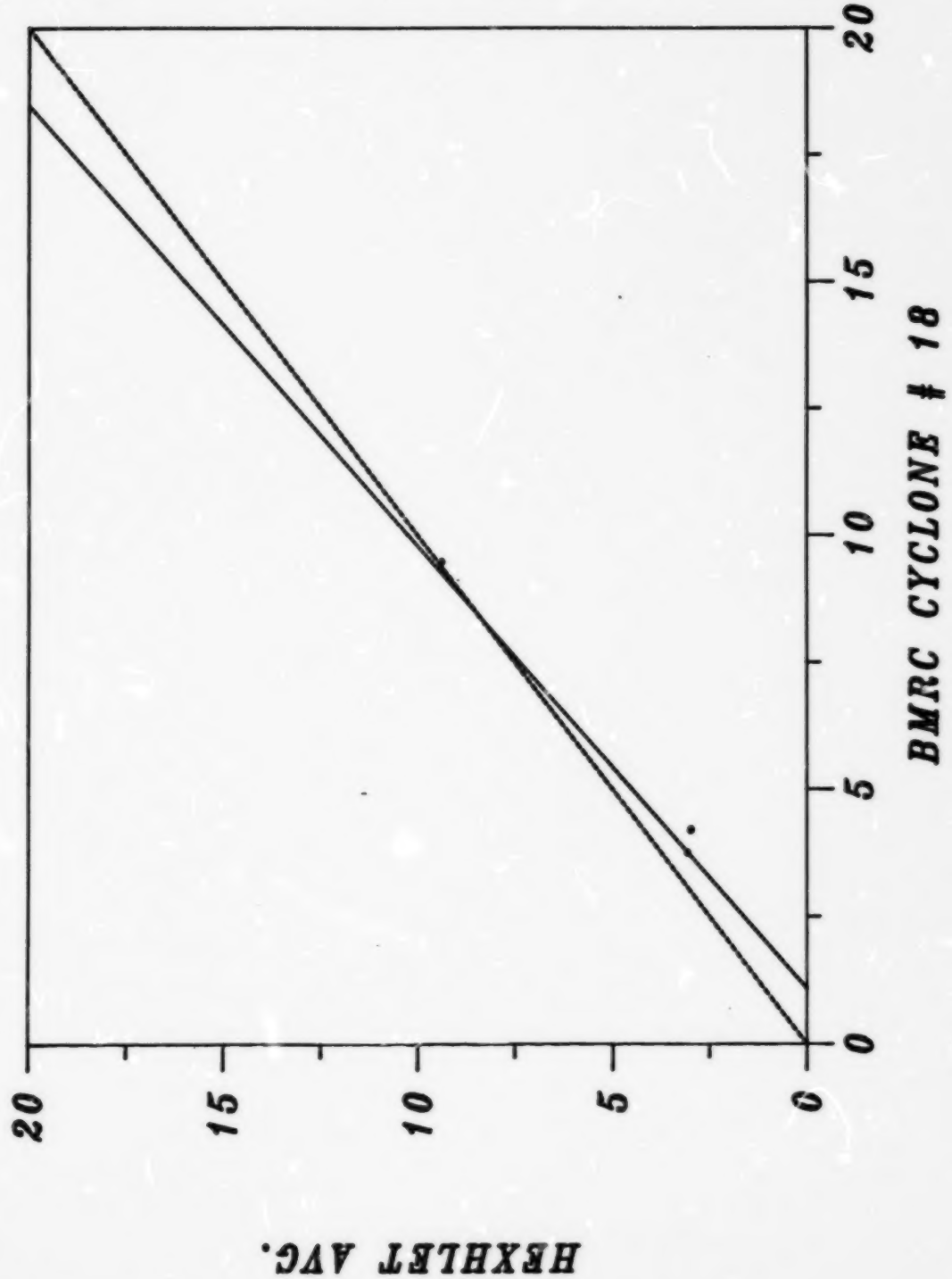
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BMRC CYCLONE # 18